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The NRL Data Base of Oblique-Incidence Soundings of the Ionosphere

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The Naval Research Laboratory has participated in a number of field exercises in support of HF communications, HF Direction Finding (HFDF), and HF Single-Site-Location (HF-SSL) systems development since 1980. During these exercises, the NRL support has included the documentation of ionospheric channel information through collection of Oblique-Incidence-Sounding (OIS) data. Data have been obtained over two distinct epochs of solar activity. The first group, obtained between 1980 and 1982, was obtained for a period of high solar activity. The second group of data obtained between 1986 and the present, corresponds to relatively low or moderate activity. This report describes a collection of approximately 167,000 ionograms in terms of the environmental conditions under which they were obtained. It is planned to make these data sets available as a resource to qualified researchers.

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CONTENTS

THE NRL DATA BASE OF OBLIQUE-INCIDENCE SOUNDINGS OF THE IONOSPHERE

1.0 Introduction

The Ionospheric Effects Branch (4180) of the Naval Research Laboratory has been collecting ionospheric data through use of the AN/TRQ-35 Chirpsounder * system since 1980. A description of the data base for the 1980-1982 period was published as NRL Memorandum Report 5452 [Goodman, 1984a]. An examination of the usefulness of oblique ionospheric sounding as an aid to frequency management has been reported [Goodman et al, 1983; Goodman and Martin, 1984; Goodman, 1984b]. The purpose of the present document is to update the original version with a description of data obtained since report 5452 was released.

A complete listing of experiments is contained in Table 1, along with the relevant dates, the equipment stations and their locations, and the type of data available.

2.0 Equipment and Data Processing

The raw ionosonde data documented herein by NRL was recovered through use of the AN/TRQ-35 system. The complete AN/TRQ-35 system typically consists of three (or four) transmitters of moderate power, a three (or four) channel receiver, and a spectrum monitor. The transmission waveform is of the chirp variety which, in comparison with sounders of the pulse variety, allows for a greater capability for interference rejection and lower power operation. No detailed description of the AN/TRQ-35 system is provided herein since such material may be found elsewhere. An early description of the Chirpsounder® technique has been given by Barry and Fenwick [1965]. A comparison of various Real-Time-Channel-Evaluation (RTCE) techniques including the chirpsounder® approach may be found in a paper by Darnell [1978]. Figure 1 shows the complement of equipment associated with a version of the AN/TRQ-35 known as the Tactical Frequency Management System (TFMS) currently being used by the DoD.

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*Chirpsounder® is a registered trademark of BR Communications.

Raw data obtained during the 1980-82 period were largely comprised of polaroid photographs which were scaled for the relevant Maximum Observable Frequencies (MOF's), the Lowest Observable Frequencies (LOF's), and the so-called FOT* bands. Figure 2 is an annotated sounding from the AN/TRQ-35. By scaling a sequence of these ionograms it is possible to develop diurnal patterns such as those in Figure 3. These plots correspond to data obtained over three mid-latitude paths, the geometry of which is given in Figure 4.

The manual scaling of the photographic output derived from the AN/TRQ-35 was a laborious procedure. Even so, much useful data has been obtained from an analysis of the scaled results. In more recent years of data collection, the process has been revamped.

Data from the RCS-4B sounder receiver in the AN/TRQ-35 complement can presently be recorded by a data collection system which was developed at NRL (see Figure 5). Although the data are developed inside the receiver in digital form, they are available externally only in analog form. The data collection system is based on a Hewlett-Packard 9000 series 300 computer equipped with an A/D converter and both fixed-disc and cartridge tape memory storage units. The computer collects ionogram data in real time, displays the ionogram on the computer CRT in the same form as seen on the sounder CRT, and records the data on the fixed disc. In its present form, the fixed disc file holds data for 291 ionograms, slightly over the amount of data produced by the sounder receiver in 24 hours of operation. Once per day the fixed-disc data are transferred to a magnetic tape cartridge for permanent archiving. A single tape cartridge utilized by NRL can store data associated with 1164 ionograms, slightly more than that produced by a single sounder receiver in four days.

Figure 6 is an example of one of the digital ionogram records. Ionogram data are compacted to minimize storage requirements. The system records the amplitudes of the HF signals received at the sounder, so the ionogram can be later reconstructed with various discrimination levels. With such post-processing it is sometimes possible to detect propagating modes not otherwise apparent. Figure 7 is an example of the same data being processed at differing discriminating levels.

3.0 Experiments and Exercises

This section provides a listing of the experiments included in the data base together with the geometries involved. Since report 5452 was published, four additional experiments/exercises have been conducted. Futhermore, as part of our on-going research, a considerable number of oblique ionograms have been

* The FOT band is taken by NRL workers to be the frequency region for which high signal strength is observed in the absence of multipath interference. It is an adaptation from the French term "FOT" which corresponds to the Optimum Working Frequency or "OWF".

obtained using a receiver located at NRL. Approximately 50,000 ionograms were listed in report 5452; over 165,000 are listed in this report. It is of interest to get some comprehension of the temporal coverage of the data sets in equivalent path-days. Typically, four ionograms/hour are obtained for a single station pair. Here a station pair is defined as a sounder circuit or path between a transmitter and a receiver. Therefore 165,000 ionograms corresponds to a coverage of 41,250 path hours or approximately 4.7 path years of data. It is noteworthy that the data have been concentrated in two epochs: 1980-82 and 1986-present. Figure 8 shows the sunspot number dependence over this period of time along with the periods of the various experiments. It will be noted that about 90% of the 1980-82 data corresponded to high solar activity conditions. In the period 1986-present, the activity was generally low to moderate.

3.1 Teamwork '80

Teamwork '80 was a NATO Marine Corps landing exercise conducted in the North Atlantic. During this exercise a representative of NRL was stationed on the USS Mt. Whitney, which was anchored off the coast of Norway. An AN/TRQ-35 receiver was located on the Mt. Whitney and transmitters were positioned at Soc Buchan (Scotland), Kolsaas (Norway), and Orland (Norway). Figure 9 depicts the geometry. Ionograms were obtained using the AN/TRQ-35 during a period of time on 18-19 September 1980. Preliminary results have been described in reports by Uffelman [1981] and Goodman and Uffelman [1982].

3.2 SURTASS-I

NRL has cooperated in two exercises in support of the U.S. Navy SURTASS System. The first was conducted in February of 1981. The experimental configuration of this initial exercise is depicted in Figure 10. During this exercise, AN/TRQ-35 transmitters were located on three (3) fixed land sites at Driver (VA), Ft. Bragg (NC), and Robins (GA). An AN/TRQ-35 receiver was placed aboard a slowly-moving ship, the R/V Moana Wave, in the Atlantic Ocean off the southeastern coast of the United States. The preliminary results of this program have been discussed by Uffelman and Harnish [1981].

3.3 Polar Sea

This particular experiment arose as an opportunity to gather high latitude ionospheric data. Originally it was planned to locate an AN/TRQ-35 system aboard a temporarily "icelocked" Coast Guard vessel positioned off the north Alaskan coast. The logistics proved too perilous, however, and as a result the transmitter component of the system was deployed to Fairbanks (Alaska) instead. Receivers were located at Anchorage (Alaska), Sacramento (CA) and the Naval Research Laboratory. The relevant geometry is provided in Figure 11.

3.4 Solid Shield

The Solid Shield exercise took place between 3 and 20 May 1981. During this period Chirpsounder transmitters and receivers were located at stations along the east coast of the U.S., and several ships operating in the Atlantic Ocean were equipped with receivers and spectrum monitors. As far as NRL was concerned, the relevant transmitters were located at Hurlbert Field (FL), and Driver (VA). Data sets were also obtained at Norfolk using AN/TRQ-35 transmissions from distant Nea Makri (Greece). Figure 12 gives the geometry. Initial results from the Solid Shield exercise have been reported by Uffelman and Harnish [1982].

3.5 Indian Ocean

The Indian Ocean exercise took place during July-August of 1981. AN/TRQ-35 receivers were located aboard two ships, the USS Kitty Hawk and the USS America, which were maneuvering in the Indian Ocean region. Transmitters utilized were located at San Miguel (Phillipines), H.E. Holt Station (Australia), Diego Garcia, and Nea Makri (Greece). Figure 13 gives the geometry.

3.6 Surtass-II

This was the second in the series of experiments designed to support the SURTASS program office. During this experiment, which was conducted in November of 1981, AN/TRQ-35 transmitters were located on the R/V Moana Wave and at Robins (GA) and Isabela (PR). The receiver at Norfolk (VA) was exploited to extract ionogram information over the three possible paths. Preliminary analyses of this data may be found in several publications, including Uffelman and Hoover [1984], and Uffelman et al [1984]. For the relevant geometry refer to Figure 14.

3.7 Classic Green TOAD

This experiment was sponsored by the U.S. Navy as a test of HF Time-Difference-of-Arrival (TDOA) and kindred techniques for HF emitter location. The experimental phase of the program was conducted during March of 1982, and it involved a number of DoD organizations and supporting contractors. NRL was involved in a number of data gathering efforts in support of this effort and the data sets included Thomson scatter profiles, using the Arecibo facility, and total electron content, using several sites in the Caribbean basin. NRL also obtained oblique-incidence ionograms, using the AN/TRQ-35. Receivers were located at Homestead (FL), Isabela (PR), and Bermuda, while a transmitter was located aboard the USNS Bartlett. Figure 15 depicts the geometry for the experiment.

3.8 Army SFBCS

This program was designed to test system concepts in conjunction with the U.S. Army Special Forces Burst Communication System. The test was conducted between June 28 and August 9, 1982. NRL was responsible for the deployment of AN/TRQ-35 assets and was fully involved in the data collection efforts. An AN/TRQ-35 receiver was located at Ft. Bragg (NC) and transmitters were located at Ft. Knox (TN), Leavenworth (KS), Ft. Lewis (WA), Isabela (PR), Driver (VA), and Patrick AFB (FL). Figure 16 gives the geometry. Results have been reported by Harnish et al [1983].

3.9 NRL SSL-BCT

During the latter part of 1982, NRL (4180) supported the U.S. Army as the architect and director of a test designed to assess the merits of two competing HF Single-Site-Location (SSL) technologies. As such, NRL was responsible for orchestration of a Baseline Certification Test (BCT) from a base-station located at Fort Ord, CA. This test, termed the SSL-BCT, was the most comprehensive one of its type and a considerable amount of ionospheric diagnostic information was obtained. It included: oblique-incidence ionograms over five paths, vertical-incidence-ionograms at three specified midpath stations, topside ionogram data, total-electron-content data from three sites, and a number of supporting data sets. A brief open source description has been prepared [Goodman and Uffelman, 1983]. A discussion of the data obtained during the SSL-BCT has been reported by Daehler [1983]. Figure 17 gives the geometry involved.

3.10 NRL Data Sets

A RCS-4B sounder receiver obtained on loan from the US Army Signal Warfare Center (SWC) has been operated sporadically for several years. Paths monitored have been those to Isabela (Puerto Rico), Driver (Norfolk, VA), Corine (Utah), Chelveston (UK), and Gibraltar (UK). Operation of this sounder has been useful for developing data-management techniques and for development of a system to measure absolute propagation-delay time. Figure 18 gives the geometry of the paths sounded using NRL as a receiver site.

3.11 Worms (FRG) Data Sets

A data collection system was established by NRL personnel at the Army Fifth Signal Command Headquarters in September 1986 to start a long-term data collection project aimed at improving MOF forecasting for HF paths in Europe. Data collection, with some interruptions, is still continuing at the time of this report. The system has been operated since installation by Fifth Signal Command personnel. Paths monitored have included those to Worms from Nea Makri (Greece), Rota (Spain), Bann-B (Ramstein AB, Germany), Chelveston (UK), and Gibraltar (UK). The work is supported by the US Army Communications Electronics Command (CECOM), Ft. Monmouth. A comparison of

some of some of the MOF data with several propagation models was included in an interim report to CECOM [Daehler 1987). Figure 19 gives the geometry of the paths which have been sounded.

3.12 ORSI

The National Security Agency (NSA) requested the Ionospheric Effects Branch to conduct a test of several techniques for analyzing Single-Site-Location HF Direction-Finding data. This test exploited an existing base-station (SSL/HFDF) at Skaggs Island, CA. As a part of this test, two RCS-4B sounder receivers located at Skaggs Island were used to monitor propagation to that station from sounder transmitters located at Robins AFB (Macon, GA), Tinker AFB (Oklahoma City, OK), Howard AFB (Panama), and Ft. Huachuca (AZ). A documented description of propagation, including identification and relative amplitudes of propagating modes at the times and frequencies relevent to the ORSI test, has been produced and is maintained on file at NRL [Goodman and Daehler, 1987]. Figure 20 gives the geometry of the paths which were sounded.

3.13 Norwegian-Based Data Sets (Operation Cold Winter)

NRL participated in a short-duration test of a modified version of IONCAP, called IONCAST, from a base station located near Evenes, Norway. The test took place between 16-27 March 1987 and involved the collection of ionograms over several paths. Locations are indicated in Table 1. The Data sets are addressed in an NRL Memorandum report [Goodman and Rhoads, 1988]. Figure 21 gives the geometry of the paths sounded.

3.14 Regency Net

The Ionospheric Effects Branch established data collection systems at Tinker AFB (Oklahoma City, OK), Ft. Huachuca (AZ), and NRL (Washington, DC) in August 1987 to provide a record of ionospheric propagation during the Pilot Network System Test 1 (PNST1) of Magnavox's equipment for Regency Net, a new strategic HF communications system under development by CECOM, Ft. Monmouth. Paths monitored were Tinker AFB and Grissom AFB (Ft. Wayne, IN) to Ft. Huachuca; Grissom AFB to Tinker AFB; and Grissom AFB and Tinker AFB to NRL. Selected data are being analyzed by the Electromagnetic Compatibility Analysis Center (ECAC) as required to assist in the evaluation of the communications equipment. Figure 22 gives the geometry of the paths sounded.

4.0 Data Base Description

4.1 General Layout

Table 1 provides certain basic information about the NRL Oblique-Incidence ionogram data base for specified experiments using the AN/TRQ-35 during 1980-82 epoch. Approximately 50,000 ionograms were obtained in photographic form and

approximately 42% of these have been scaled for "routine" parameters such as the MOF, LOF, and the FOT band. These parameters have been recorded on magnetic tape cartridges for convenience in preliminary analysis and for plotting purposes. In addition, since the beginning of 1982, all raw analog ionogram traces have been recorded on magnetic tape as well. This has assisted the development of automated analysis approaches. Since 1986, roughly 117,000 ionograms have been obtained in digital form.

Table 2 gives a breakdown of ionograms partitioned in accordance with the following rules:

A. GEOGRAPHICAL AREA:

Longitudinal differences are ignored (even though they are certain to exist) and we only consider latitudinal dependencies, which generally thought to be more pronounced. The following selections were made on the basis of the locations of the midpoints of the paths in question.

HIGH	:	$\lvert latitude \rvert \geq$	60°
MIDDLE	:	$20 \leq \lvert latitude \rvert <$	60°
LOW	:	$\lvert latitude \rvert <$	20°

The vertical bars refer to absolute values.

B. SEASON:

WINTER	:	December 22 - March 21
EQUINOX	:	March 22 - June 21 and September 22 - December 21
SUMMER	:	June 22 - September 21

Definitions for the summer and winter for the Southern Hemisphere are reversed.

C. TIME OF DAY:

DAY	:	0800 - 1600
TRANSITION	:	1600 - 2000 and 0400 - 0800
NIGHT	:	2000-0400

Local time at the path midpoint ("control point") is used. Note that there are eight hours for each epoch.

D. SUNSPOT ACTIVITY:

HIGH	:	$R_I \geq 100$
MEDIUM	:	$50 \leq R_I < 100$
LOW	:	$0 \leq R_I < 50$

Here R_I is the (daily) International Relative Sunspot Number. R_I is used in the majority of cases but some portion of the 1980-82 period involved the specification of the Zurich sunspot number R_z (now defunct).

E. MAGNETIC ACTIVITY:

DISTURBED	:	$a_p \geq 80$
MODERATE	:	$15 \leq a_p < 80$
QUIET	:	$0 \leq a_p < 15$

Here a_p is the planetary magnetic activity index. The relationship between the index a_p and the more familiar quasi-logarithmic index K_p may be found in a number of references (viz., Mayaud [1980])

F. PATH DISTANCE (KILOMETERS)

VERY LONG	:	$d \geq 4000$
LONG	:	$3000 \leq d < 4000$
MEDIUM	:	$2000 \leq d < 3000$
SHORT	:	$1000 \leq d < 2000$
VERY SHORT	:	$500 \leq d < 1000$
ULTRA SHORT	:	$0 \leq d < 500$

Both R_I and a_p are obtained from the Solar-Geophysical Data (prompt) Reports issued by NOAA (see for example Coffey and McKinnon [1987]). Table 3 is a set of composite distributions for the 1980-1982 period, the 1986 - present period, and the full period. "Pie-chart" representations of the data in Table 3 are provided in Figures 23-25.

5.0 Comments on the Distribution of the Data Sets

The vast majority of the data has been obtained over mid-latitude paths (i.e., 91%) while 7% has been obtained over low latitude paths and about 2% of the ionograms are representative of high latitudes. There would appear to be a clear need to obtain data sets in other than the mid-latitude region. In view of the considerable interest in high latitude performance prediction, priority consideration for data collection in the future is directed toward the auroral zone and polar cap regions.

The seasonal distribution would appear to be reasonable, although it would appear that some steps should be taken to obtain more wintertime data, which now corresponds to about 18% of a three-part total.

As expected, the diurnal distribution is uniform; this is a result of the fact the data are generally collected continuously - around the clock - for any given exercise/operation.

As indicated earlier, the 1980-1982 epoch was dominated by high solar conditions (i.e., 88%) of the time while the 1986-present epoch was largely representative of low solar activity (i.e., 90%). The composite distribution was: 26% for high, 9% for moderate, and 65% for the low activity cases. The fact that the ratio of the number of ionograms obtained during 1980-82 to those obtained during 1986-present was 0.42 (rather than one-to-one) caused the composite percentage of low solar activity ionograms to be significantly larger.

The ionograms were obtained over either largely quiet (i.e., 71%) or only moderately disturbed conditions (i.e., 28%). The 1% remaining were obtained during conditions which are defined as disturbed. Of course the reader is reminded that 1% of the data base corresponds to roughly 1700 ionograms --- still a healthy number.

The distribution of path lengths is not unreasonable, with only 19% in excess of a canonical maximum limit for 1-hop F2 mode propagation (i.e., 4000 km). This category is termed "very long". The "short" to "long" category (i.e., $1000 \leq d < 4000$ km) comprises 51% of the data. About 22% of the ionograms are in the Near-Vertical-Incidence-Skywave (or NVIS) domain or just beyond. These latter paths should be useful in the analysis of short-haul tactical links.

6.0 Future Activities

6.1 Data Collection

NRL is continuing to accumulate ionograms using the system described in Section 2. Data is to be collected at NRL throughout 1988 except during periods for which the AN/TRQ-35 system is required for field operations. Also, data from Worms (FRG) will be obtained on an irregular basis in support of the 5th Signal Command in Europe. Future operations anticipated during 1988 include ORSI II in May-June, involving data collection over moderate to long paths but emphasizing the 1500 km path between Colorado Springs, CO and Skaggs Island, CA. A second operation will likely involve further support of the U.S. Army Regency Net Program during the late summer of '88. Finally, we anticipate obtaining additional data in the fall of 1988 over a number of mid-latitude paths terminating at Ft. Huachuca, AZ in support of an Army HFSSL Program.

6.2 Equipment Modification

The AN/TRQ-35 sounder system provides ionograms in which the relative times of arrival of incoming signals are displayed as a function of frequency. While this information is important for frequency management purposes, the usefulness of the data could be greatly increased if the time scale were calibrated to give the absolute propagation delay time. With absolute timing, it is possible to derive the profile of electron density as a function of altitude. In contrast to MOF and time-delay spread measurements, which are indeed useful as measures of propagation effectiveness, the electron density profile is a description of the ionosphere itself, and therefore important for studying the morphology and time variations of the propagating medium. This information can be expected to be important for improving propagation models and for further developing updating methods, in which near-real-time sounder measurements are used as a correction to propagation model forecasts of MOFs or multimode conditions.

NOTE: In the absence of an absolute (organic) measurement of time delay, two other methods may be employed to solve the problem. The first method may involve the exploitation of a vertical incidence sounder located near the oblique path midpoint or control point. The second method requires the presence of a readily-identifiable mode such as ground waves (only useful for short paths) or sporadic E, both of which are used as a height reference. The ground wave is naturally associated with a reference altitude of zero kilometers while the sporadic E returns are taken as arising from scatterers at 100 km altitude (and at a range determined by the path length and ionospheric height). Since the AN/TRQ-35 preserves the relative positions of the ionospheric echoes, such an approach will yield an absolute ionogram subject to the accuracy of the assumption of the sporadic E height. However, it must be stated that the most profitable and exacting approach involves the systematic removal of the problem rather than treating the symptoms.

Equipment is currently being set up to permit absolute calibration of ionograms from the RCS-4B receiver. The procedure is to measure the start times of each transmitter frequency sweep and of each receiver scan, to a precision of one microsecond or better. In the current procedure, the transmitter start times will be measured relative to a cesium frequency standard, and then calibrated relative to Universal Coordinated Time (UCT) by occasionally comparing the cesium standard pulses with timing signals from a Global Positioning System (GPS) receiver. The start time of the receiver scan will be measured routinely with the GPS receiver.

7.0 Recommendations for Further Work

7.1 Improved Absolute Propagation-delay Measurements:

While the method currently underway for measuring absolute propagation-delay time is expected to demonstrate the feasibility and usefulness of the measurements, it is not suitable for extended or routine measurements because it will involve frequency transfers of the GPS receiver from the sounder receiver location to the sounder transmitter location. The obvious solution is the addition of a second GPS receiver, which would then make routine and long-term measurements possible.

7.2. Automatic Ionogram Scaling:

Whereas sounder measurements are valuable for frequency selection on a sounded path, their use is labor-intensive and requires highly-trained personnel. Therefore the widespread application of sounders to frequency management over a large geographical area is limited. Part of this problem could be solved by automatic interpretation of oblique-incidence ionograms, similar to procedures which have been developed for interpreting vertical-

incidence-sounder data. The task should be relatively simple for well-formed ionograms, and extremely difficult for ionograms which are abnormal or correspond to extremely poor propagation. It seems probable, however that a system which could automatically handle something like 90% of all ionograms could be developed. The time required to analyze the remaining cases could probably also be shortened by a semi-automatic interpretation scheme, in which the automatic system would take over after a human observer's initial interpretation.

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TABLE 1

List of NRL Experiments During Which Ionograms were Obtained

OPERATION and DATE PATH ID	PATH #	RCVR/ XMTR	DEGREES LAT.	LON.	MEDIA ANALOG	DIGITAL
TEAMWORK '80 (15SE80-23SE80)					PHOTOS	CARTRIDGE
USS MT.WHITNEY (SHIP)		R	COAST OF N.ATLANTIC			TAPE
KOLSAAS,NOR	P.1	X	60.0 N	10.3 E		88%
ROBINS AFB,GA	P.2	X	32.633N	83.583W		
SOC BUCHAN,SCOT	P.2	X	57.3 N	1.5 W		
OERLAND,NOR	P.3	X	63.7 N	9.7 E		
SURTASS I (15FE81 - 23FE81)					PHOTOS	CARTRIDGE
R/V MOANA WAVE (SHIP)		R	SE COAST OF U.S.			TAPE
DRIVER,VA	P.1	X	36.817N	76.500W		89%
ROBINS AFB,GA	P.2	X	32.633N	83.583W		
FT.BRAGG,NC	P.3	X	35.015N	78.983W		
POLAR SEA (02AP81 - 15AP81)					PHOTOS	CARTRIDGE
FAIRBANKS,AK		R	64.850N	147.717W		TAPE
CHESAP.BAY DIV.,MD	P.1	X	38.067N	76.417W		28%
ELMONDORF(ANCHORAGE),AK	P.2	X	61.217N	149.883W		
SACRAMENTO,CA	P.3	X	38.583N	121.500W		
SOLID SHIELD (03MY81-19MY81)					PHOTOS	CARTRIDGE
FT.BRAGG,NC		R	35.150N	78.983W		TAPE
DRIVER,VA	P.1	X	36.817N	76.500W		100%
HURLBERT FLD.,FL	P.2	X	30.3 N	86.4 W		
SHAW AFB,SC	P.2	X	33.967N	80.483W		
MACDILL AFB,FL	P.3	X	27.850N	82.483W		
NORFOLK (NAVCAMSLANT),VA		R	36.950N	76.300W		
CAMP LEJEUNE,NC (BOGUE FIELD)	P.1	X	34.667N	77.350W		
NEA MAKRI (MARATHON),GR	P.1	X	38.063N	28.983E		
DRIVER,VA	P.2	X	36.817N	76.500W		
MACDILL AFB,FL	P.2,P.3	X	27.850N	82.483W		
HURLBERT FLD.,FL	P.3	X	30.3 N	86.4 W		
SHAW AFB,SC	P.3	X	33.967N	80.483W		
INDIAN OCEAN (25JL81-24AU81)					PHOTOS	CARTRIDGE
USS AMERICA (SHIP)		R	INDIAN OCEAN			TAPE
SAN MIGUEL,PHIL.	P.1	X	15.150N	120.983E		16%
DIEGO GARCIA	P.2	X	7.333S	72.417E		
H.E.HOLT(NW CAPE),AUSTL	P.3	X	21.750S	114.167E		
NEA MAKRI (MARATHON),GR	P.3	X	38.083N	23.983E		
USS KITTY HAWK (SHIP)		R	INDIAN OCEAN			
SAN MIGUEL,PHIL	P.1	X	15.150N	120.983E		
DIEGO GARCIA	P.2	X	7.333S	72.417E		
H.E.HOLT(NW CAPE)AUSTL	P.3	X	21.750S	114.167E		
NEA MAKRI (MARATHON),GR	P.3	X	38.083N	23.983E		
SURTASS II (10NO81 - 22NO81)					PHOTOS	CARTRIDGE
NORFOLK (NAVCAMSLANT),VA		R	36.950N	76.300W		TAPE
ROBINS AFB,GA	P.1	X	32.633N	83.583W		100%
ISABELA,PR	P.2	X	18.500N	67.017W		
R/V MOANA WAVE(SHIP)	P.3	X	SE COAST OF U.S.			

TABLE 1 (Cont'd.)

OPERATION and PATH ID	DATE PATH #	RCVR/ XMTR	DEGREES LAT.	LON.	MEDIA ANALOG	DIGITAL
CLASSIC TOAD (19MR82-29MR82)					PHOTOS	CARTRIDGE
USNS BARTLETT (SHIP)		R	SE COAST OF U.S.		MAGNETIC	TAPE
HOMESTEAD AFB, FL	P.1	X	25.483N	80.383W	TAPE	82%
ISABELA, PR	P.2	X	18.500N	67.017W		
BERMUDA (TUDOR HILL)	P.3	X	32.333N	64.750E		
SFBCS (28JN82 - 09AU82)					PHOTOS/	
FT.BRAGG, NC		R	35.150N	78.983W	MAGNETIC	
FT.KNOX, TN	P.1	X	37.900N	85.950W	TAPE	
FT.LEAVENWORTH, KS	P.2	X	39.317N	95.917W		
FT.LEWIS, WA	P.3	X	47.139N	122.589W		
FT.BRAGG, NC		R	35.150N	78.983W		
ISABELA, PR	P.1	X	18.500N	67.017W		
DRIVER, VA	P.2	X	36.817N	76.500W		
PATRICK AFB, FL	P.3	X	28.250N	80.600W		
SSL-BCT (29NO82 - 18DE82)					PHOTOS/	CARTRIDGE
FT.ORD, CA		R	36.652N	121.735W	MAGNETIC	TAPE
CHINA LAKE NWC, CA	ZONE 1	X	35.662N	117.622W	TAPE	100%
NELLIS AFB, NV	ZONE 2	X	36.250N	115.033W		
LUKE AFB, AZ	ZONE 3	X	33.535N	112.382W		
FT.ORD, CA		R	36.652N	121.735W		
ERIE, CO	ZONE 4	X	40.100N	105.047W		
SAN DIEGO, CA	ZONE 5	X	32.708N	117.246W		
FT.LEWIS, WA	ZONE 6	X	47.139N	122.589W		
NRL (13AU86 - 10JN87)						CARTRIDGE
NRL		R	38.817N	77.017W		TAPE
ISABELA, PR	P.1	X	18.500N	67.017W		100%
ROTA, SP	P.1	X	36.617N	6.350W		
CORINNE, UT	P.2	X	41.583N	112.420W		
DRIVER, VA	P.3	X	36.817N	76.500W		
GRIBRALTOR, SP	P.3	X	36.183N	5.367W		
CHELVESTON, UK	P.3	X	52.300N	0.517W		
WORMS (03OC86 - 10JN87)						CARTRIDGE
WORMS, GE		R	49.633N	8.367E		TAPE
PIRMASENS, GE	P.1	X	49.200N	7.600E		100%
ROTA, SP	P.1	X	36.617N	6.350W		
BREMERHAVEN, GE	P.1	X	53.533N	8.583E		
BANN B, GE	P.1, P.2	X	49.383N	7.600E		
SIGONELLA, IT	P.1, P.3	X	37.400N	14.917E		
NELLINGEN, GE	P.2	X	48.717N	9.267E		
EDINGEN, GE	P.3	X	49.450N	8.617E		
NEA MAKRI (MARATHON), GR	P.3	X	38.083N	23.983E		
ORSI (09JA87 - 20FE87)						CARTRIDGE
SKAGGS ISLAND, CA		R	38.183N	122.383W		TAPE
FT.HUACHUCA, AZ	P.1	X	31.550N	110.333W		100%
ROBINS AFB, GA	P.2	X	32.633N	83.583W		
TINKER AFB, OK	P.3	X	35.417N	97.400W		

TABLE 1 (Cont'd.)

OPERATION and DATE PATH ID	PATH #	RCVR/ XMTR	DEGREES LAT.	 LON.	MEDIA ANALOG	 DIGITAL
ORSI cont'd(09JA87 - 20FE87)						
SKAGGS ISLAND, CA		R	38.183N	122.383W		
ISABELA, PR	P.1	X	18.500N	67.017W		
HOWARD AFB, PANAMA	P.2	X	9.500N	79.500W		
DRIVER, VA	P.3	X	36.817N	76.500W		
NORWAY (19MR87 - 25MR87)						CARTRIDGE
EVENES (NARVIK), NOR		R	68.433N	17.417E		TAPE
EVENES (NARVIK), NOR	P.1	X	68.433N	17.417E		100%
MILLTOWN, UK	P.1	X	57.667N	3.567W		
BODO, NOR	P.2	X	67.283N	14.283E		
CHELVESTON, UK	P.2	X	52.300N	0.517W		
THURSO, UK	P.3	X	58.600N	3.500W		
HELGELANDSMOEN, NOR	P.3	X	60.100N	10.217E		
REG.NET'87 (14AU87 - 29SE87)						CARTRIDGE
NRL (WASH., DC)		R	35.900N	77.017W		TAPE
TINKER AFB, OK	P.1	X	35.417N	97.400W		100%
DRIVER, VA	P.2	X	36.817N	76.500W		
GRISSOM AFB, IN	P.3	X	40.667N	86.133W		
FT.HUACHUCA, AZ		R	31.550N	110.333W		
DRIVER, VA	P.1	X	36.817N	76.500W		
TINKER AFB, OK	P.2	X	35.417N	97.400W		
GRISSOM AFB, IN	P.3	X	40.667N	86.133W		
TINKER AFB, OK		R	35.417N	97.400W		
DRIVER, VA	P.1	X	36.817N	76.500W		
GRISSOM AFB, IN	P.2	X	40.667N	86.133W		

TABLE 2

OPERATION	TOTAL	A	B	C	D	E	F	
TEAMWORK		H 100%	W	D 33%	H 67%	D	VL 2%	S
'80	851	M	E	T 36%	M 33%	M	L	VS 35%
		L	S 100%	N 31%	L	Q 100%	M	US 63%
		H	W 100%	D 33%	H 89%	D	VL	S 100%
SURTASS I	2,088	M 100%	E	T 34%	M 11%	M	L	VS
		L	S	N 33%	L	Q 100%	M	US
		H 31%	W	D 34%	H 100%	D 14%	VL 38%	S
POLAR SEA	3,700	M 69%	E 100%	T 33%	M	M 14%	L 30%	VS
		L	S	N 33%	L	Q 72%	M	US 32%
SOLID		H	W	D 34%	H 100%	D	VL .5%	S 23.6%
SHIELD	8,465	M 100%	E 100%	T 33%	M	M 47%	L	VS27.3%
		L	S	N 33%	L	Q 53%	M	US48.6%
INDIAN		H	W	D 33%	H 100%	D 3%	VL 67%	S 17%
OCEAN	15,798	M 23%	E	T 33%	M	M 39%	L 16%	VS
		L 77%	S 100%	N 34%	L	Q 58%	M	US
		H	W	D 33%	H 69%	D	VL	S 16%
SURTASS II	2,973	M 100%	E 100%	T 33%	M 31%	M 62%	L	VS 42%
		L	S	N 34%	L	Q 38%	M 42%	US
CLASSIC		H	W 23%	D 33%	H 100%	D	VL	S 66%
GREEN	5,448	M 100%	E 77%	T 33%	M	M 27%	L	VS 34%
TOAD		L	S	N 34%	L	Q 53%	M	US
		H	W	D 33%	H 39%	D 7%	VL	S 21%
SFBCS	5,962	M 100%	E	T 34%	M 20%	M 68%	L 23%	VS 34%
		L	S 100%	N 33%	L 41%	Q 25%	M 11%	US 11%
		H	W	D 25%	H 85%	D	VL	S 31%
SSL-BCT	4,347	M 100%	E 100%	T 34%	M 15%	M 70%	L	VS 52%
		L	S	N 41%	L	Q 30%	M	US 17%
		H	W	D 34%	H	D 1%	VL 40%	S
NRL	38,125	M 100%	E 75%	T 33%	M 10%	M 18%	L 18%	VS
as of 10JN87		L	S 25%	N 33%	L 90%	Q 81%	M 17%	US 25%
		H	W 27%	D 37%	H	D	VL	S 44%
WORMS	27,128	M 100%	E 56%	T 32%	M 9%	M 9%	L	VS
as of 31OC87		L	S 17%	N 31%	L 91%	Q 91%	M	US 56%
		H	W 100%	D 34%	H	D	VL 23%	S 20%
ORSI	18,881	M 100%	E	T 33%	M	M 7%	L 37%	VS
		L	S	N 33%	L 100%	Q 93%	M 20%	US
		H 100%	W 34%	D 29%	H	D	VL	S 67%
NORWAY	517	M	E 66%	T 34%	M	M 29%	L	VS 15%
		L	S	N 37%	L 100%	Q 71%	M 7%	US 11%
REGENCY		H	W	D 33%	H	D	VL	S 50%
NET '87	32,544	M 100%	E 17%	T 33%	M 15%	M 45%	L 12%	VS 13%
		L	S 83%	N 34%	L 85%	Q 55%	M 12%	US 13%

TABLE 3

OPERATION	TOTAL	A	B	C	D	E	F
		H 4%	W 6%	D 33%	H 88%	D 3%	VL 24% S 27%
TOTALS	49,632	M 71%	E 48%	T 33%	M 7%	M 42%	L 10% VS 20%
		L 25%	S 46%	N 34%	L 5%	Q 55%	M 4% US 15%

1980 thru 1982 OPERATIONS

OPERATION	TOTAL	A	B	C	D	E	F
		H .5%	23%	D 34%	H	D .3%	VL 16% S 28%
TOTALS	117,195	M 99.5%	E 42%	T 33%	M 10%	M 21.7%	L 15% VS 4%
		L	S 35%	N 33%	L 90%	Q 78 %	M 12% US 25%

1986 THRU PRESENT OPERATIONS

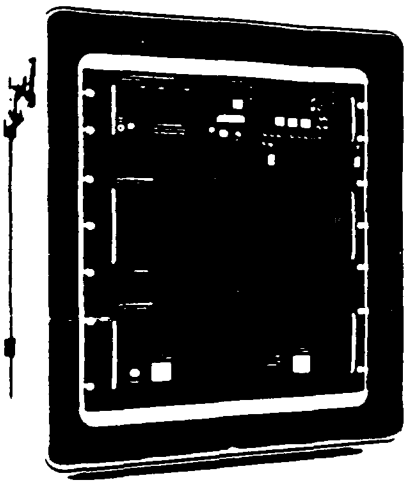
OPERATION	TOTAL	A	B	C	D	E	F
		H 2%	W 18%	D 34%	H 26%	D 1%	VL 19% S 27%
TOTALS	166,827	M 91%	E 44%	T 33%	M 9%	M 28%	L 14% VS 8%
		L 7%	S 38%	N 33%	L 65%	Q 71%	M 10% US 22%

TOTAL OPERATIONS

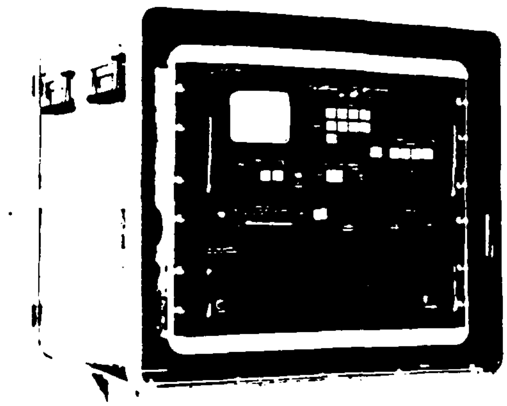
KEY:

A = Geographic Area
B = Season
C = Time of Day
D = Sunspot Number
E = Magnetic Activity
F = Path Distance

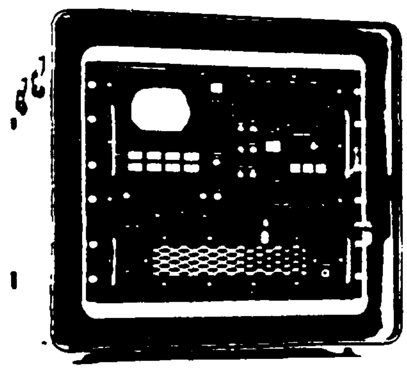
AN/TRQ-35 OBLIQUE SOUNDING EQUIPMENT



CHIRP TRANSMITTER



SPECTRUM MONITOR



CHIRP RECEIVER

Figure 1: Photographs of AN/TRQ-35 components, including an oblique-incidence sounder transmitter and receiver of the type used for the measurements described in this report.

ANNOTATED SOUNDING FROM THE CHIRP SOUNDER

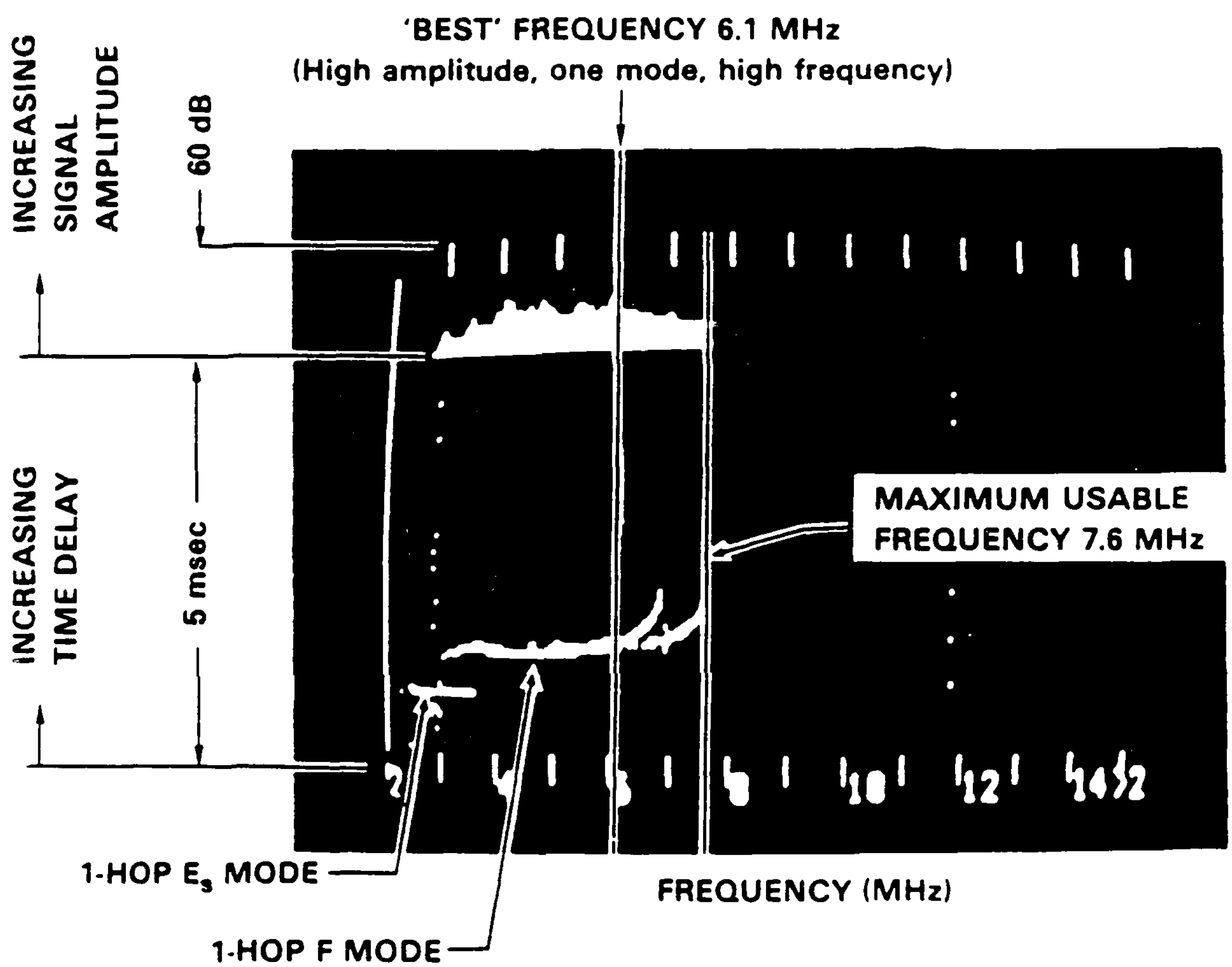


Figure 2: Oblique-Incidence ionogram produced by the AN/TRQ-35 sounder system, indicating the quantitative information available from it.

MEASURED MOF, LOF, AND FOT

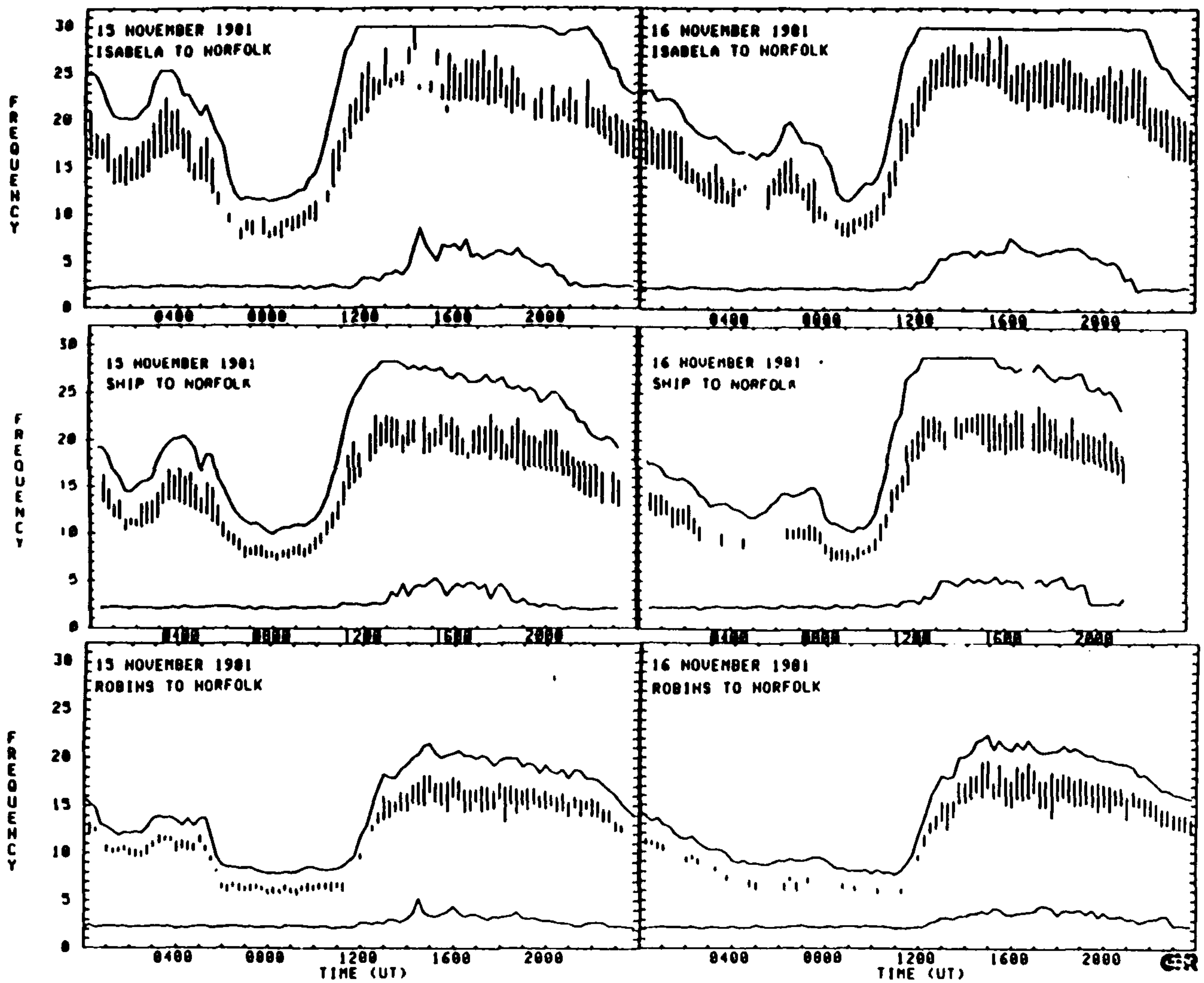


Figure 3: Measured MOF, LOF, and FOT for 15-16 November 1981 in the mid-Atlantic region.

Figure 4: Experimental configuration of a November 1981 HF Communications Test.

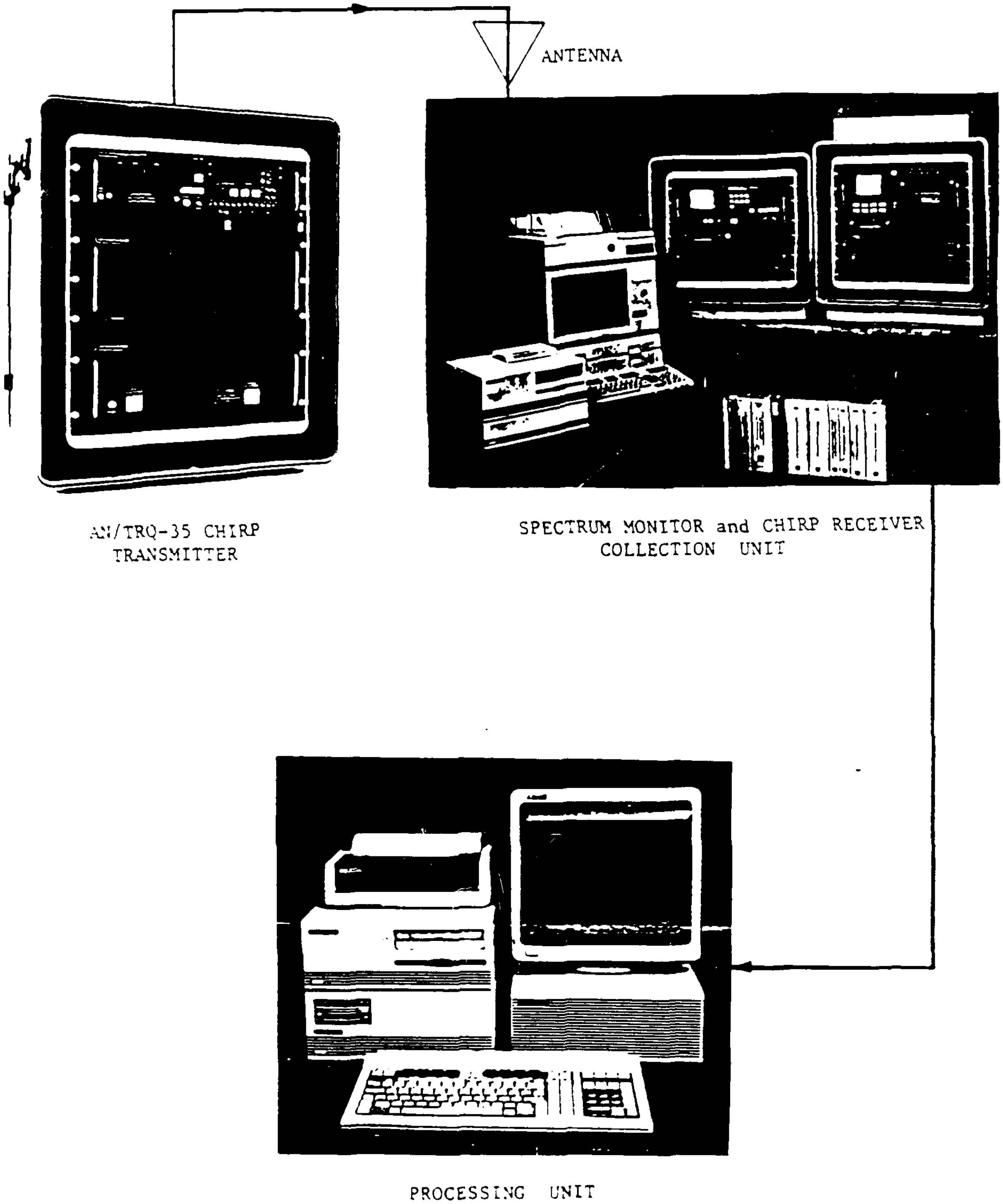


Figure 5: Photographs illustrating the oblique-incidence sounder equipment and the automatic data processing equipment used to record the ionogram information.

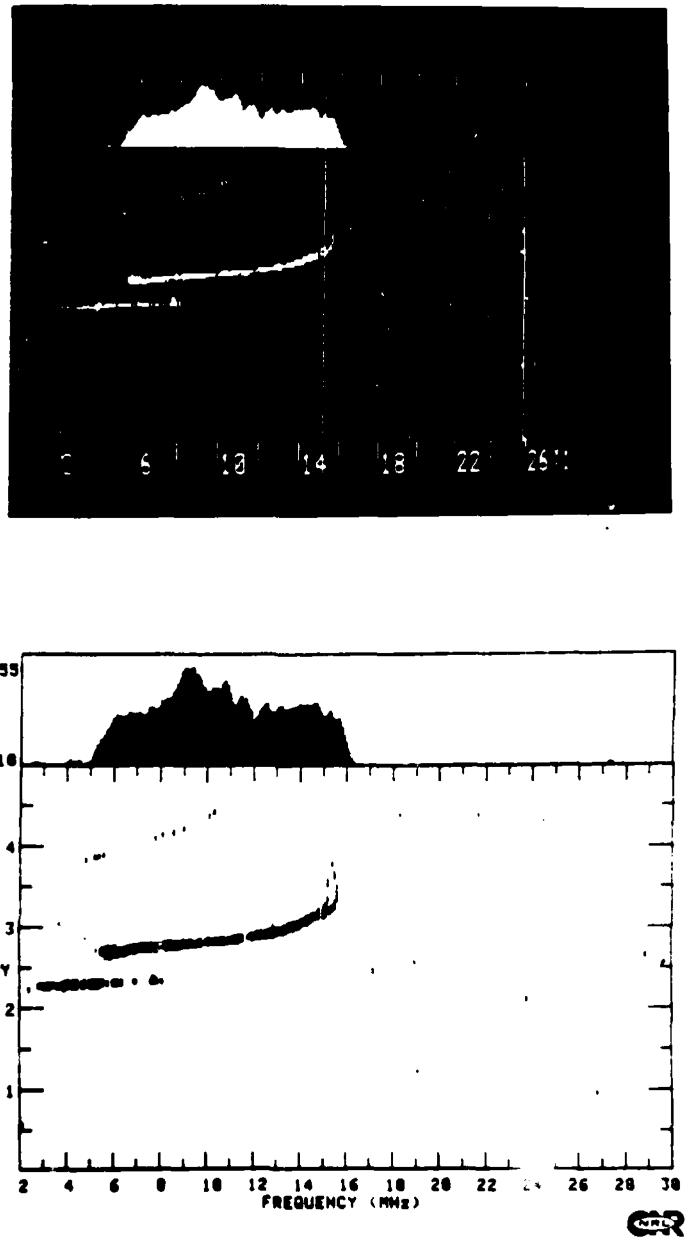


Figure 6: Ionogram observed 1982 November 30, 2045Z over the Ft. Ord - Nellis AFB path.

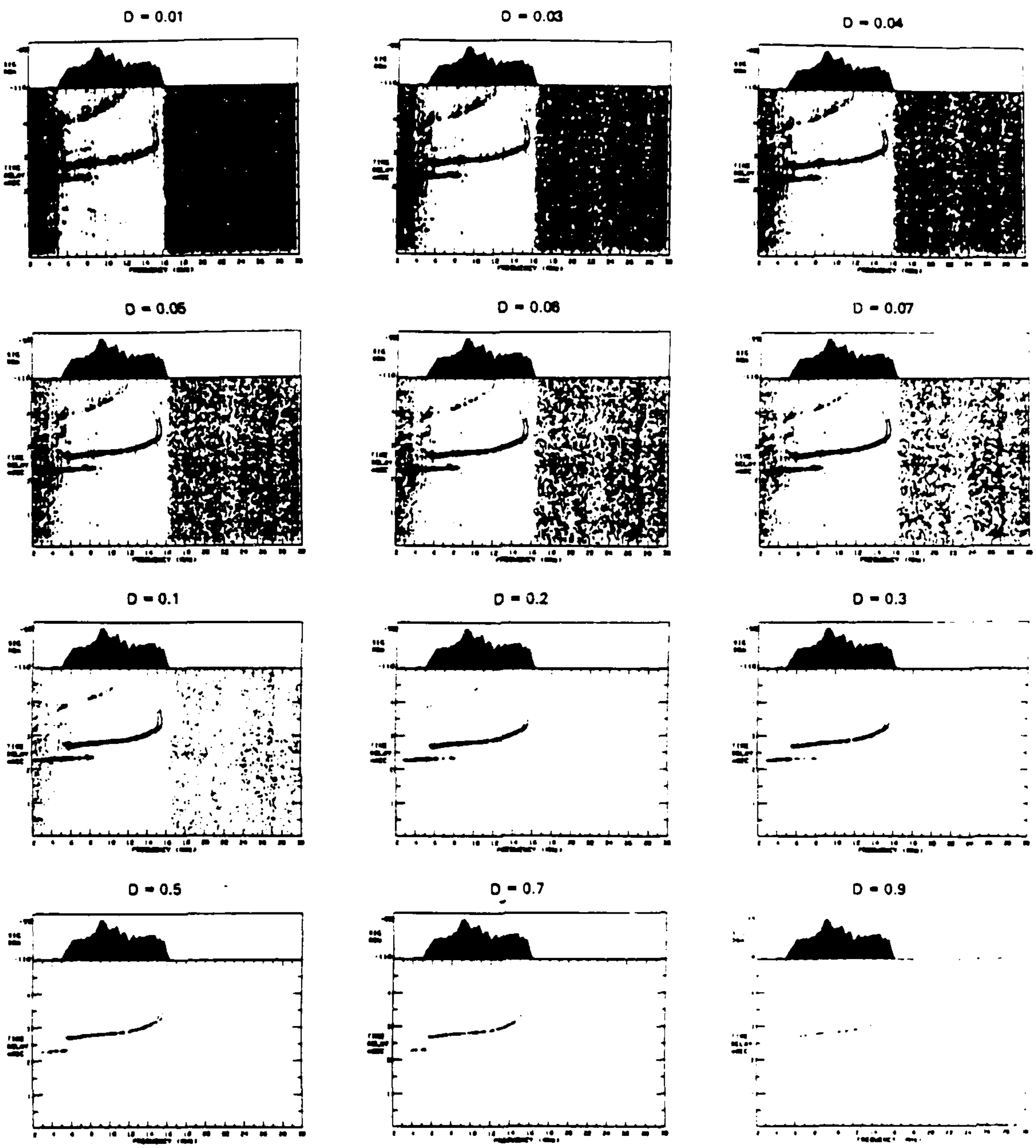


Figure 7: The ionogram from Figure 6 displayed using different values of discrimination level D (= signal strength as a fraction of the maximum observed signal strength). Only those frequency-time delay points are plotted for which the signal strength exceeds the discrimination level.

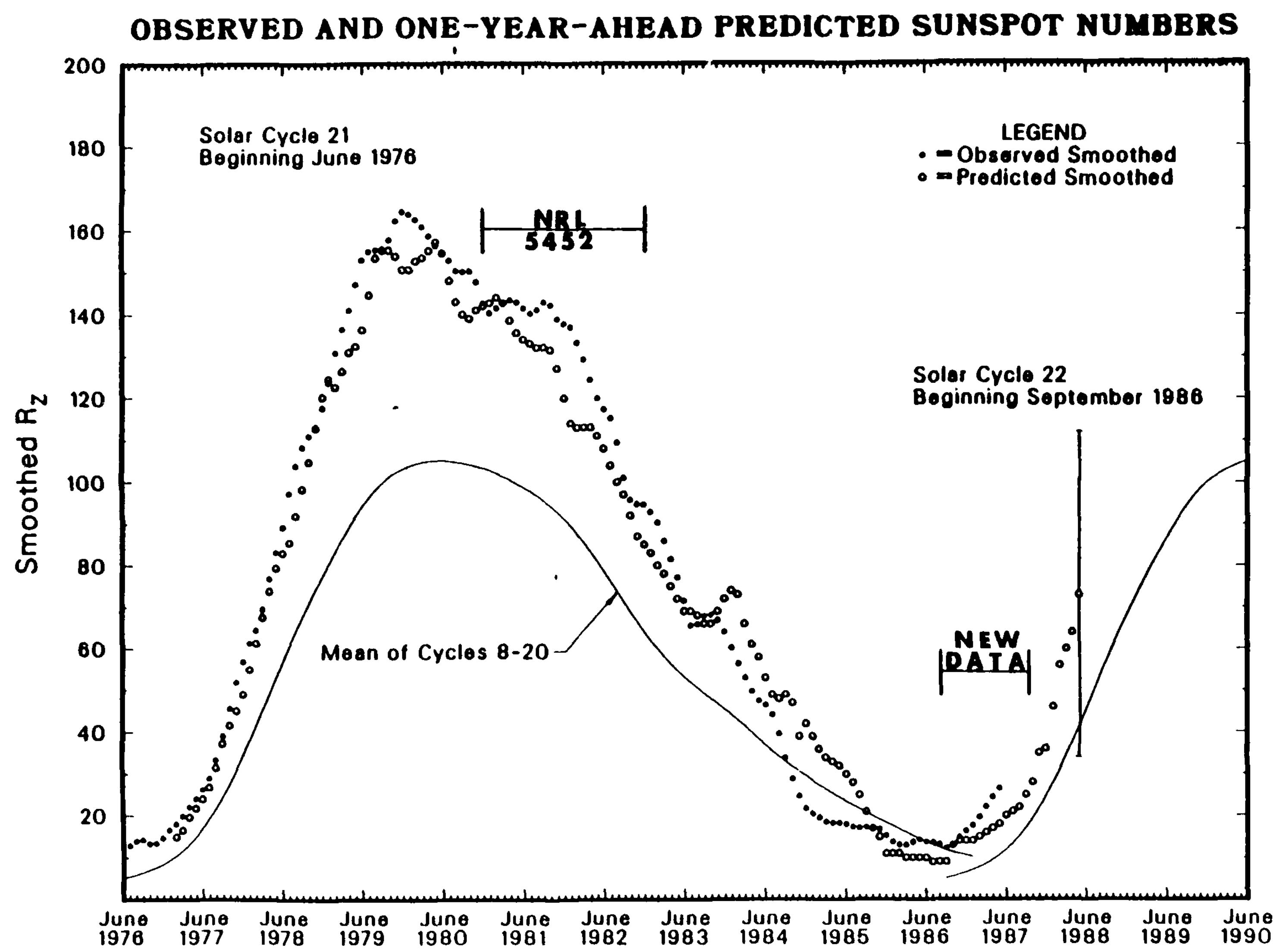


Figure 8: Variations in sunspot number between 1976 and 1988.

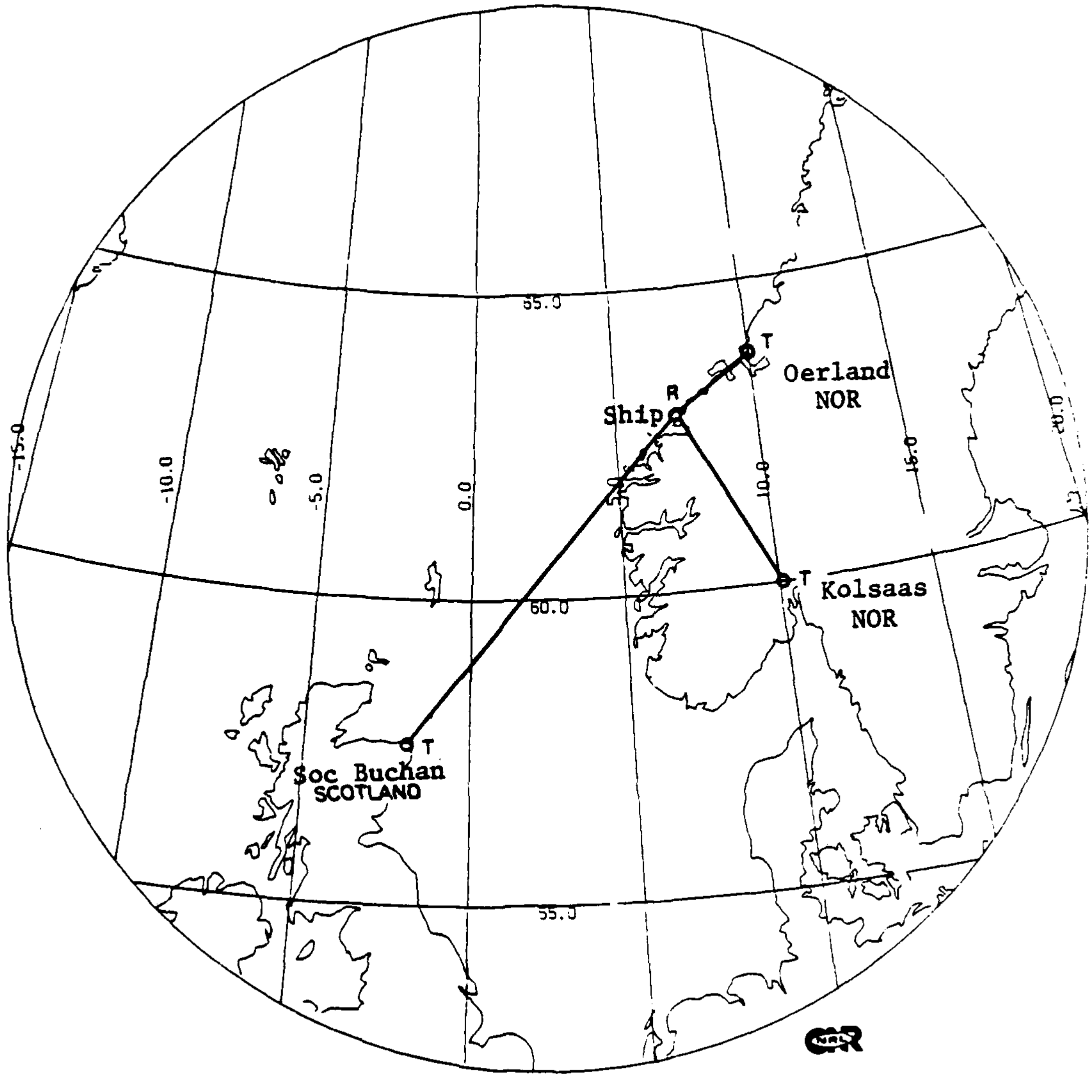


Figure 9: Map showing the location of sounder equipment during the Teamwork '80 exercise. In this and the following figures, "T" indicates a sounder transmitter and "R" indicates a sounder receiver.

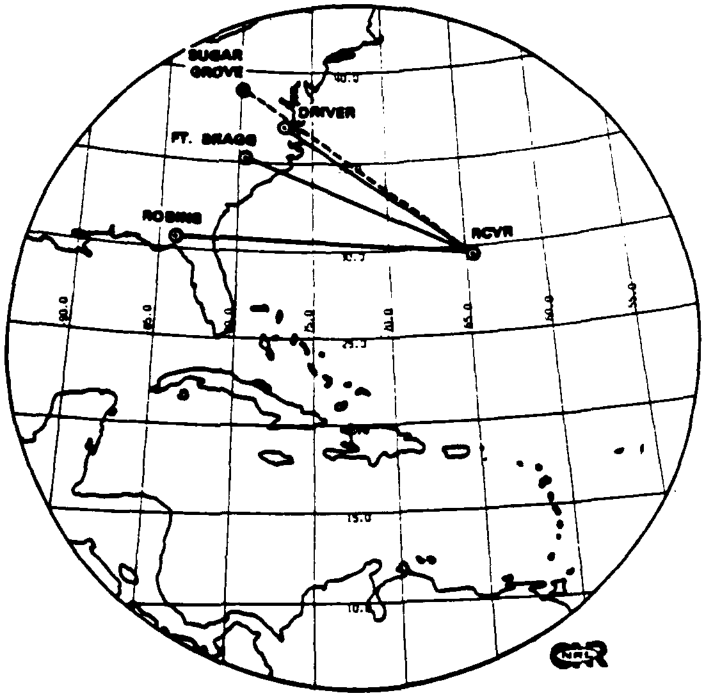


Figure 10. Map showing the location of sounder equipment during the SURTASS I experiment.

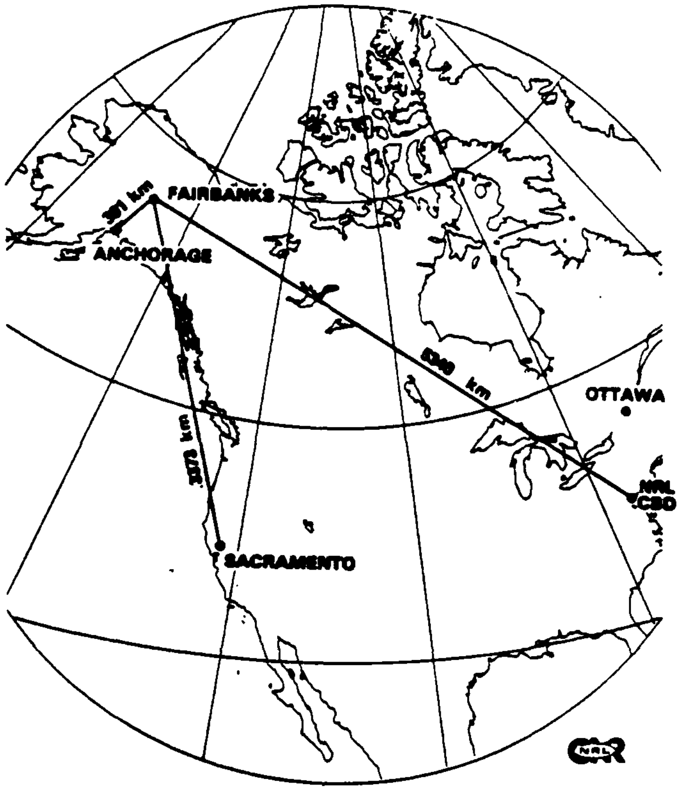


Figure 11: Map showing the location of sounder equipment during the Polar Sea experiment.

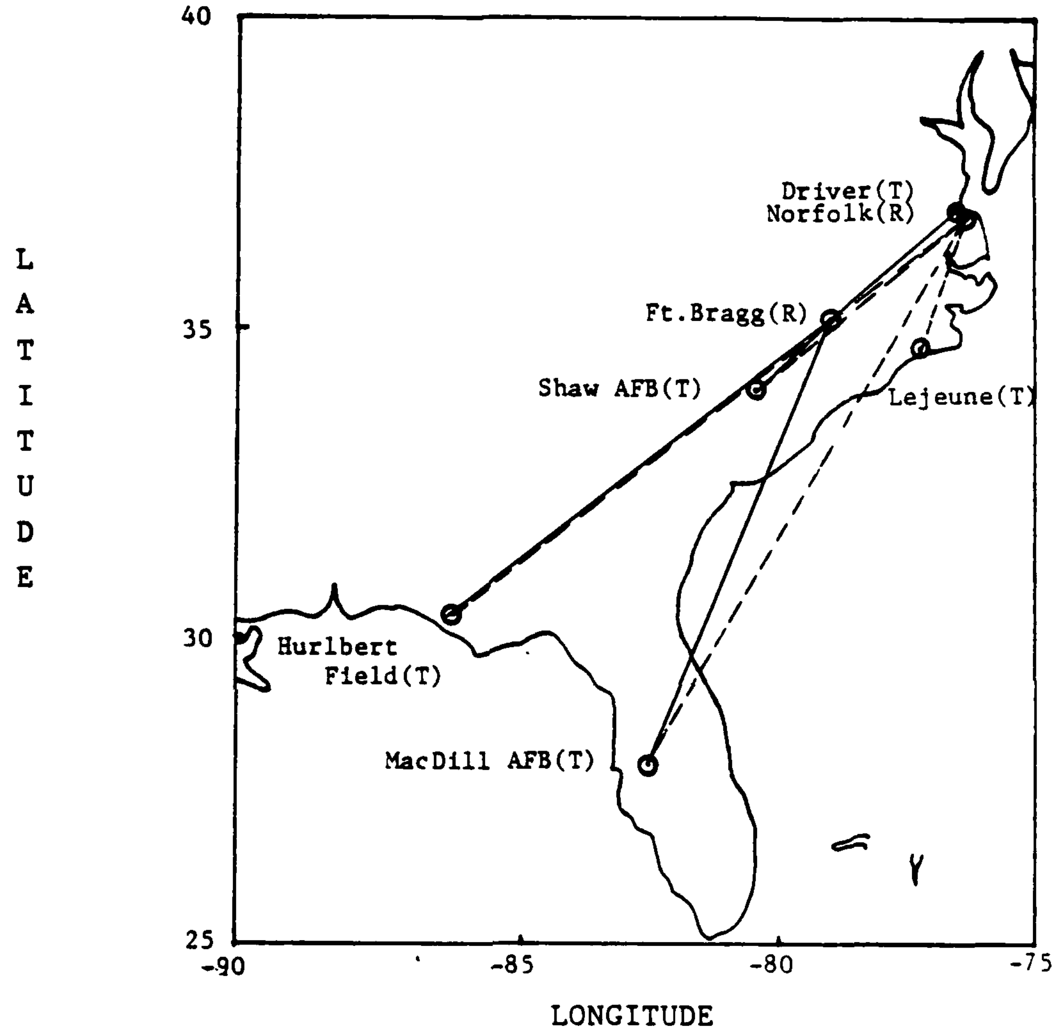


Figure 12: Map showing the location of sounder equipment during the Solid Shield experiment.

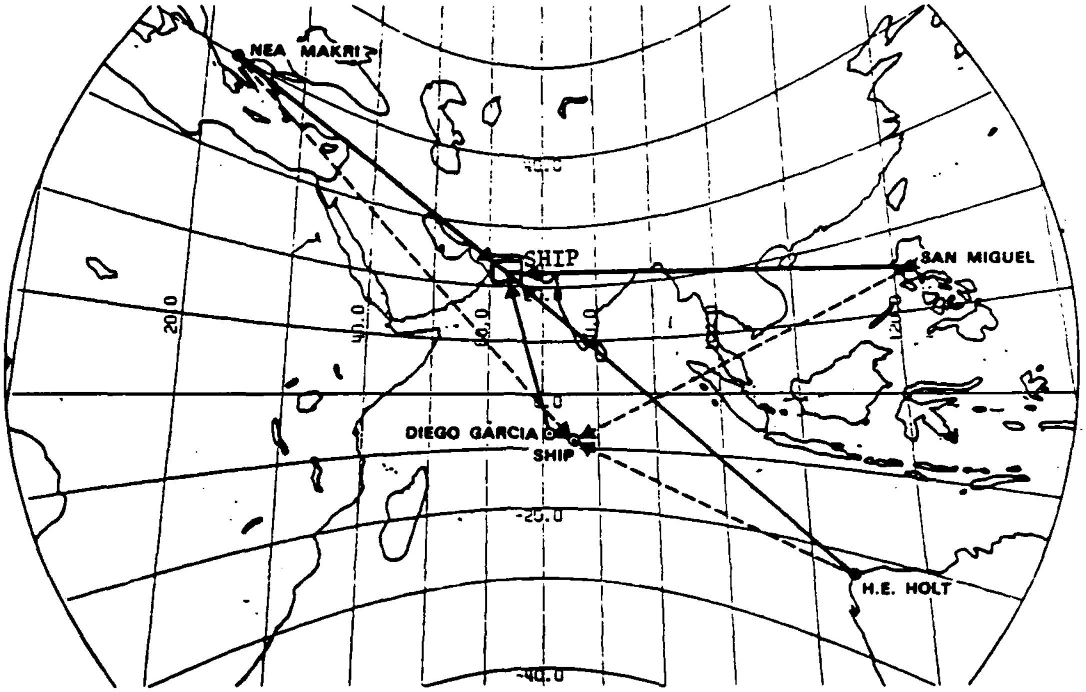


Figure 13: **Map showing the location of sounder equipment during the Indian Ocean experiment.**

Figure 14: Map showing the location of sounder equipment during the SURTASS II experiment.

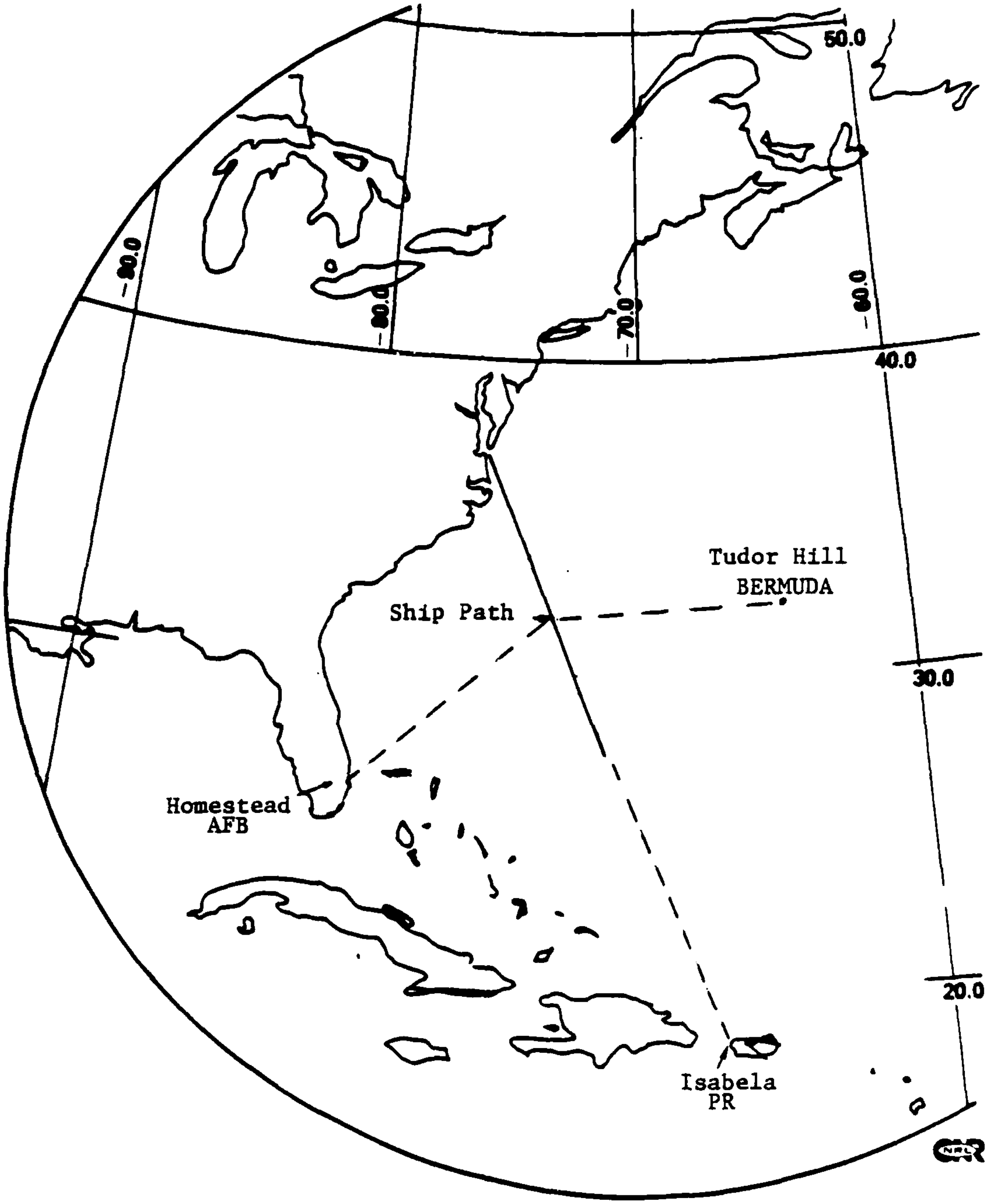


Figure 15: Map showing the location of sounder equipment during the Classic Green Toad experiment.

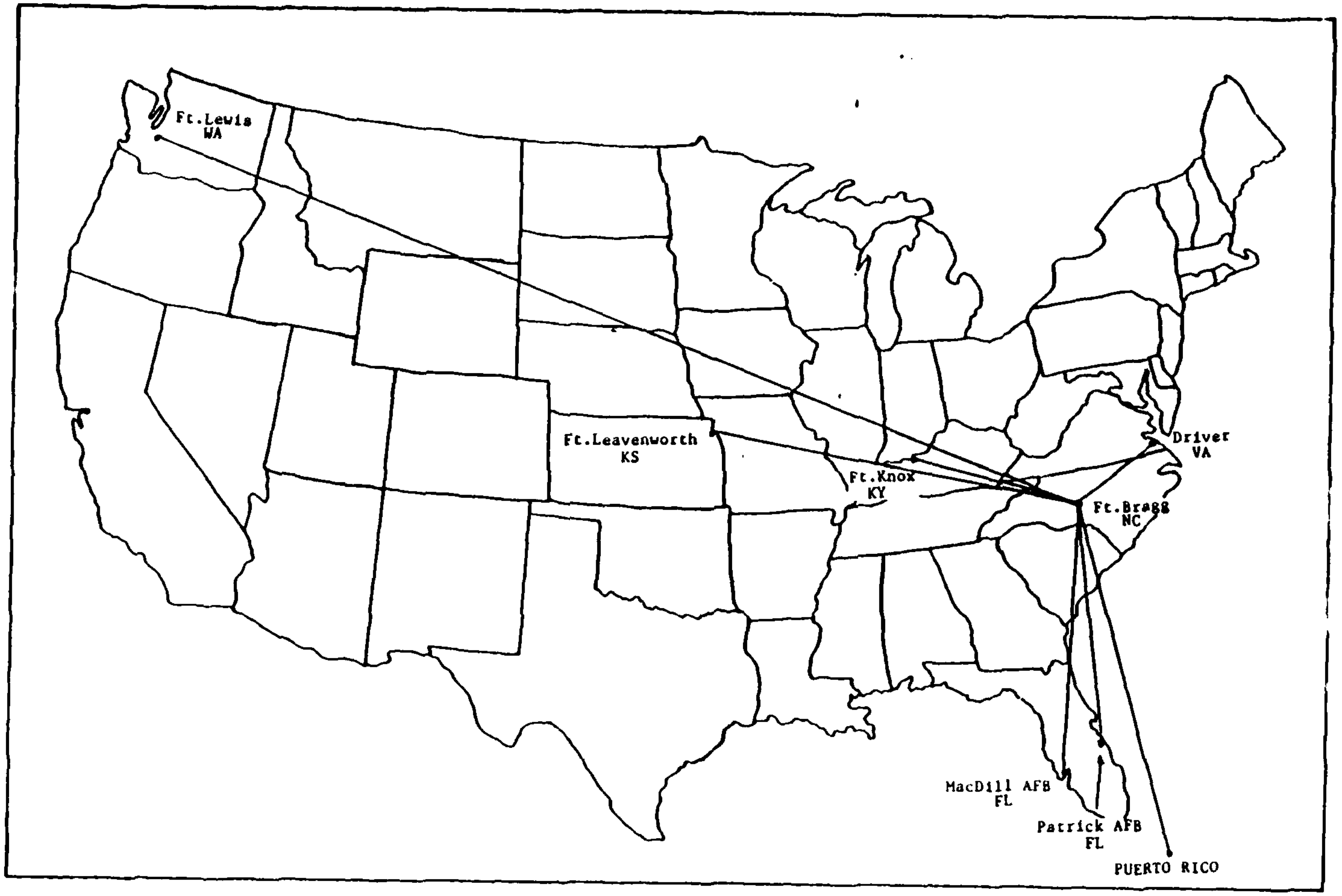


Figure 16: Map showing the location of sounder equipment during the Army Special Forces Burst Communication System (SFBCS) test.

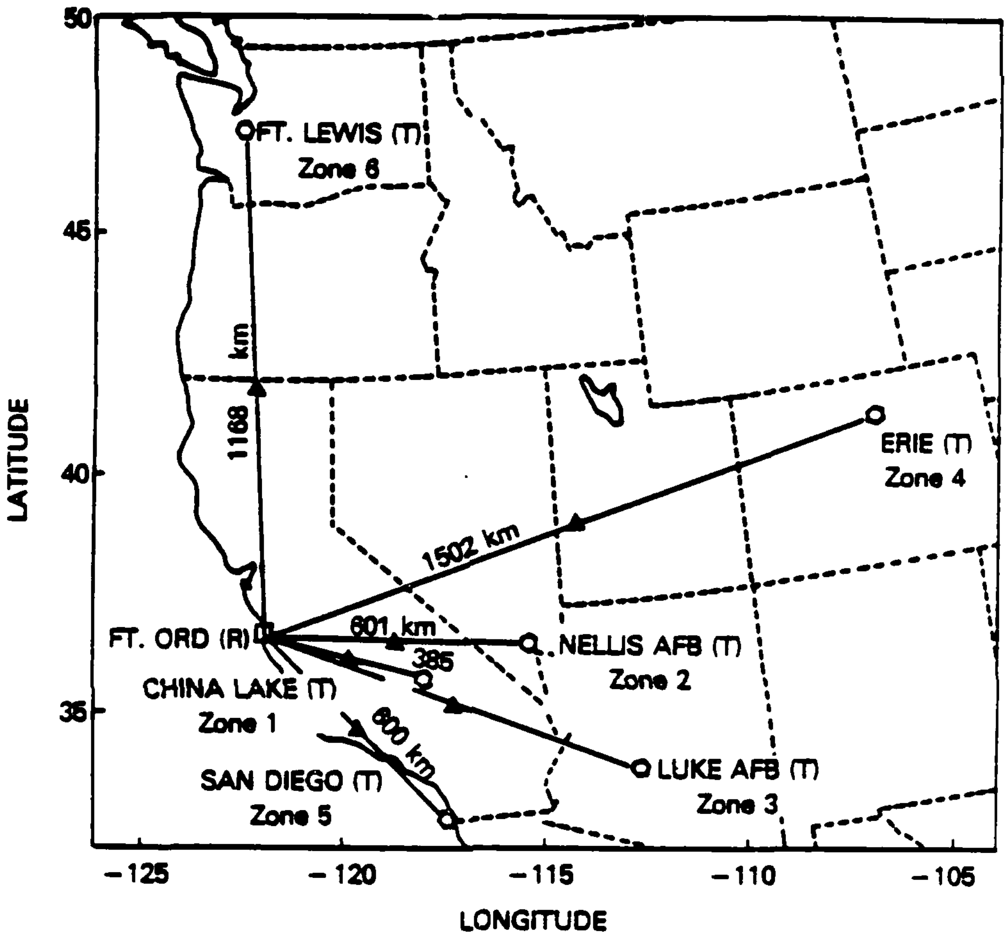


Figure 17: Map showing the location of sounder equipment during the Single-Site-Location Baseline Configuration Test (SSL-BCT).

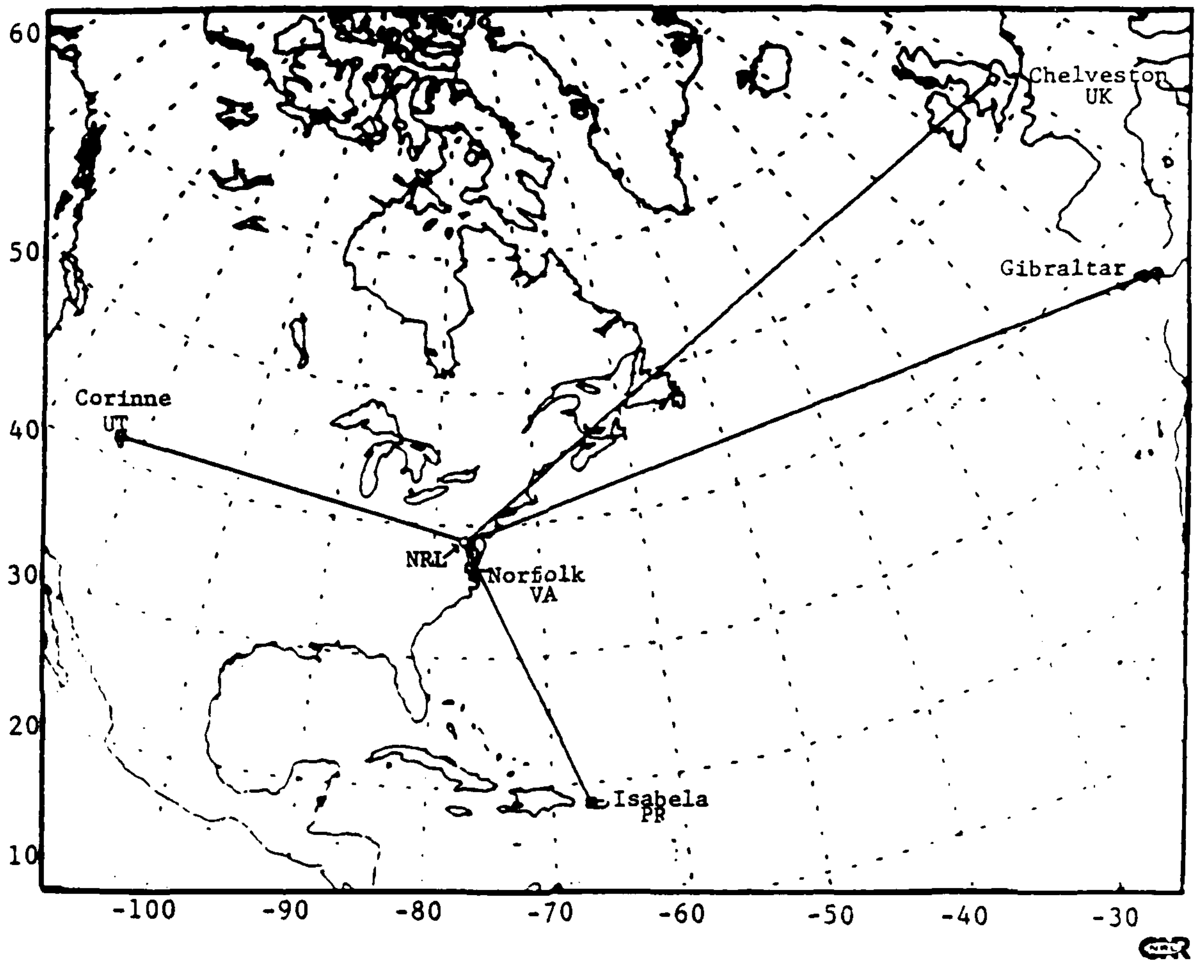


Figure 18: Map showing the location of sounder transmitters monitored from time to time with a receiver at NRL.

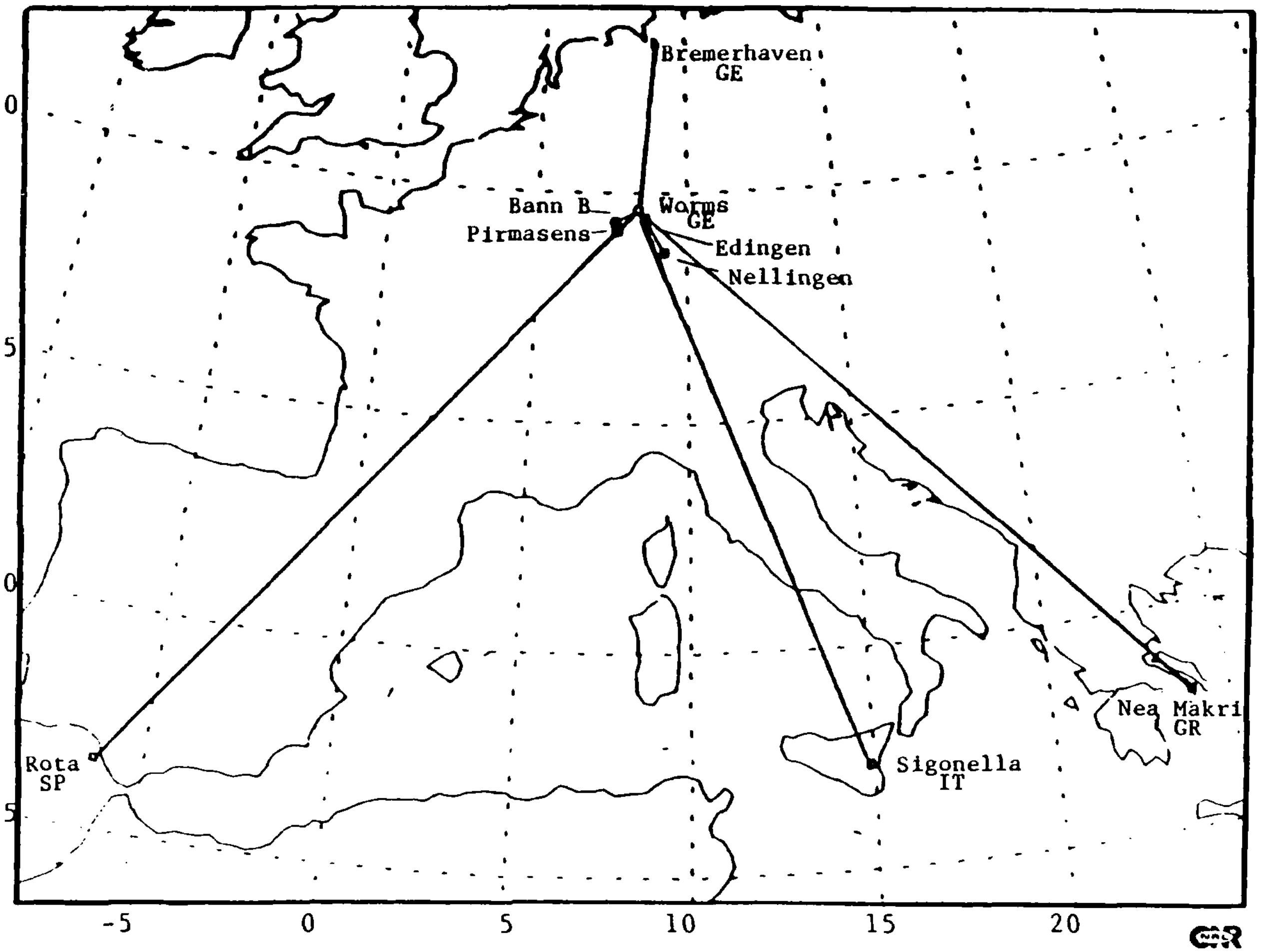


Figure 19: Map showing the location of sounder equipment during Army exercises at Worms, Germany.

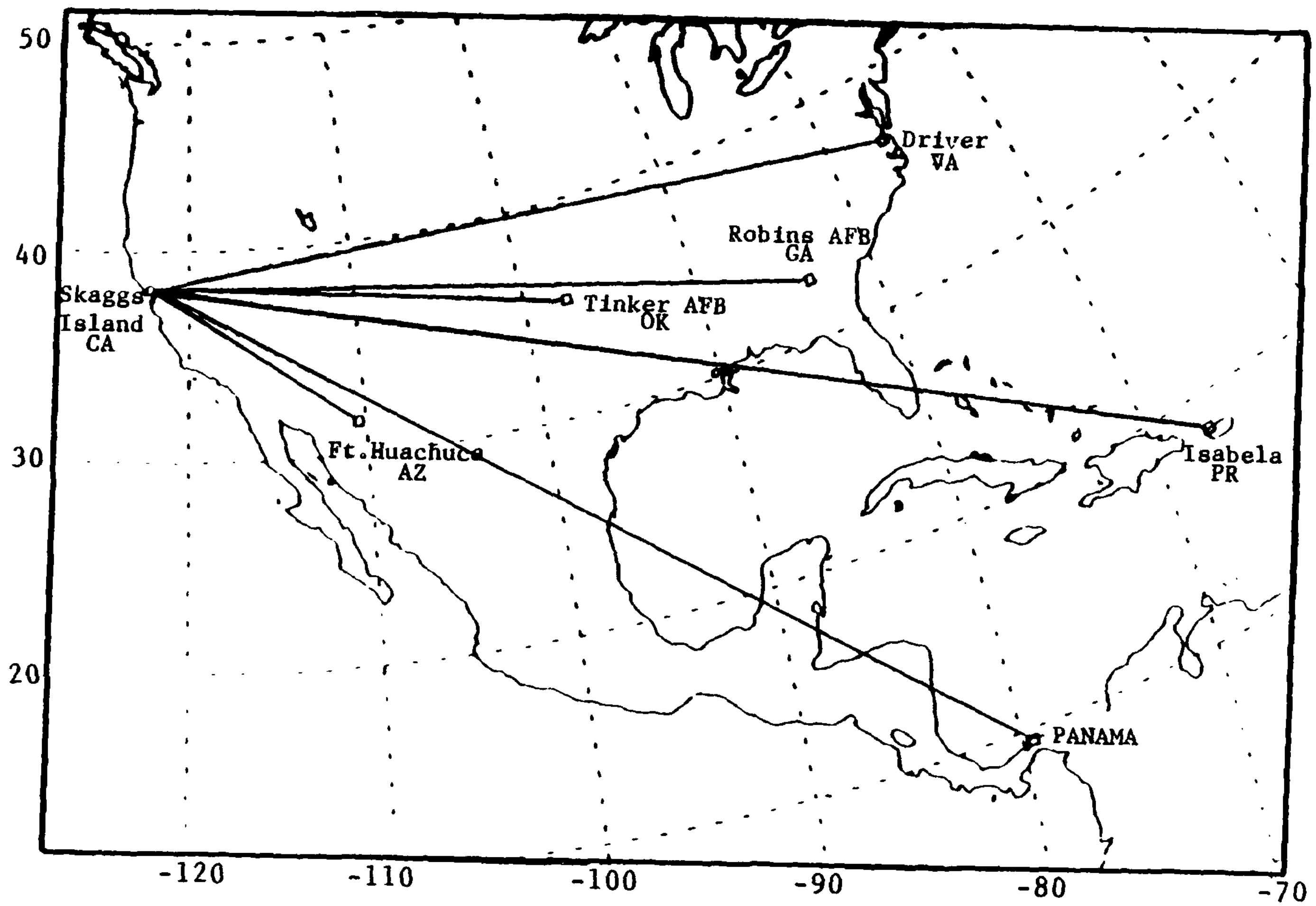


Figure 20: Map showing the location of sounder equipment during the ORSI 1 test.

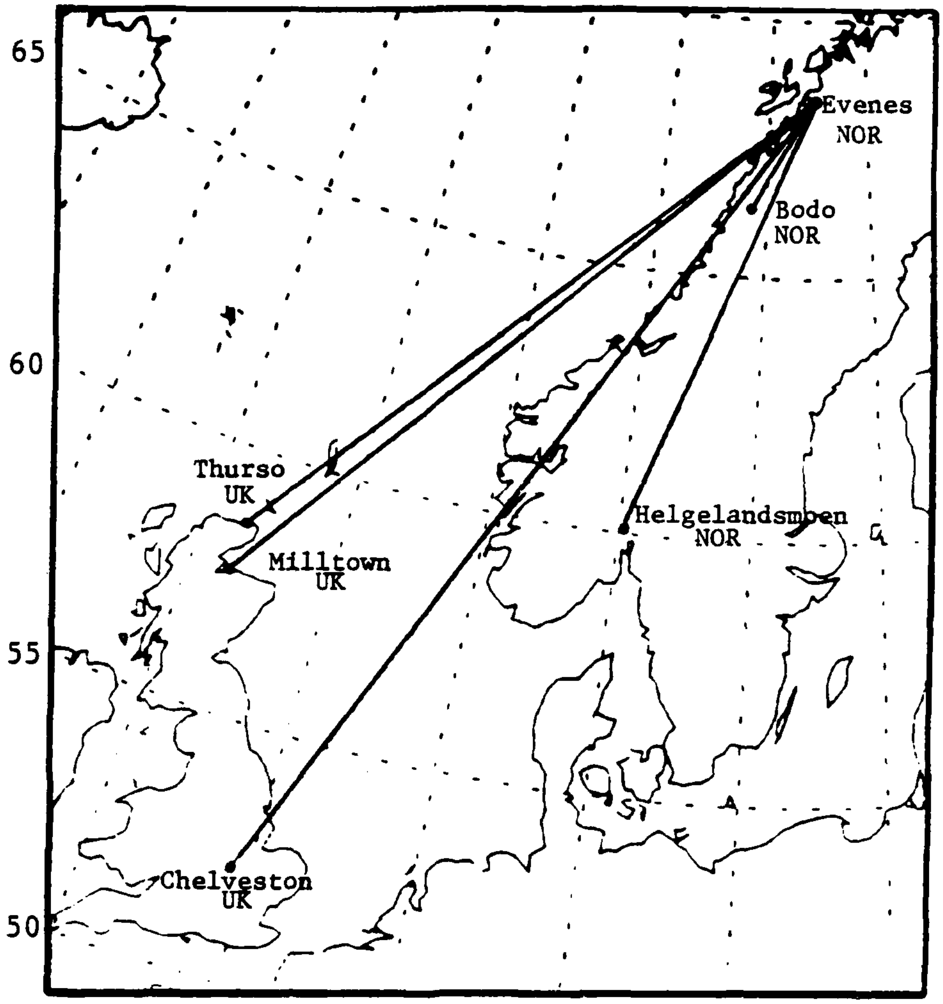


Figure 21: Map showing the location of sounder equipment during the operation Cold Winter.

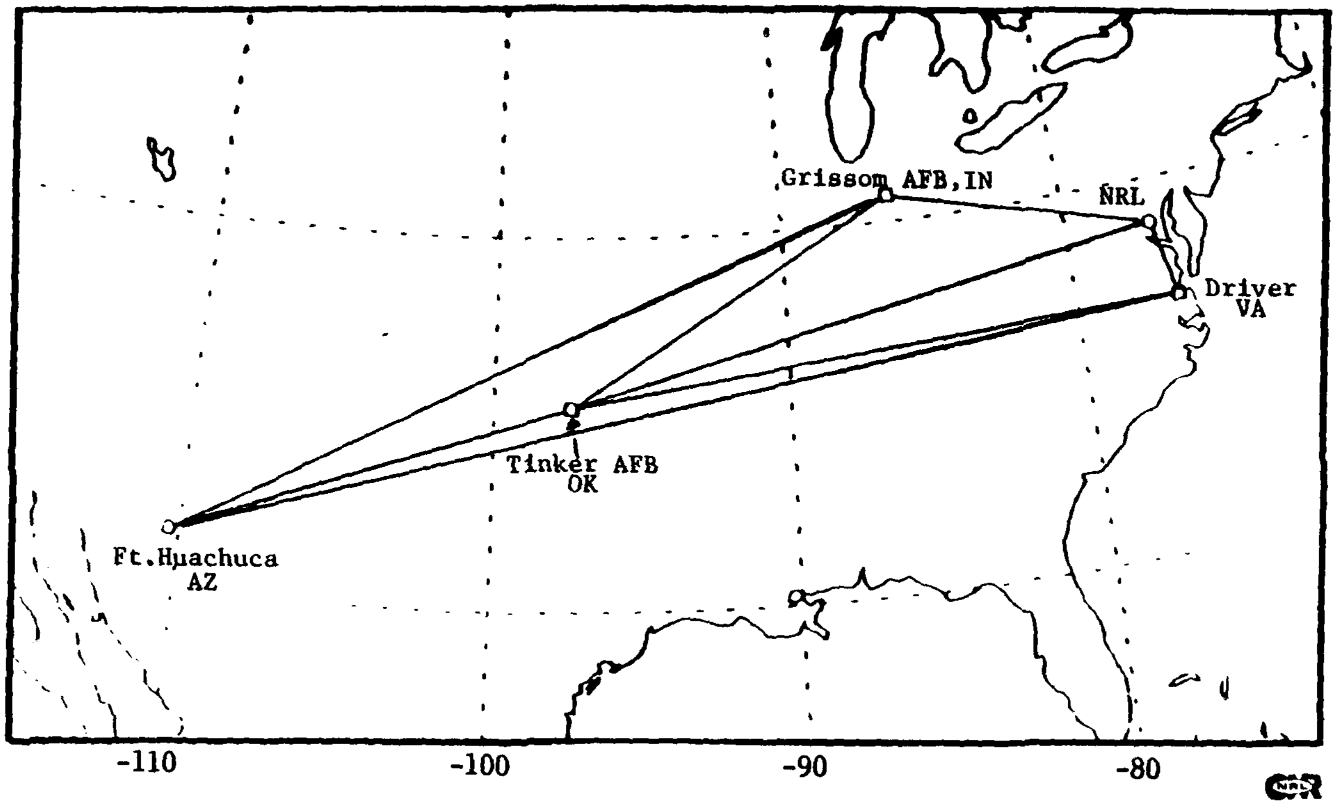


Figure 22: Map showing the location of sounder equipment during the Regency Net PNST1 test.

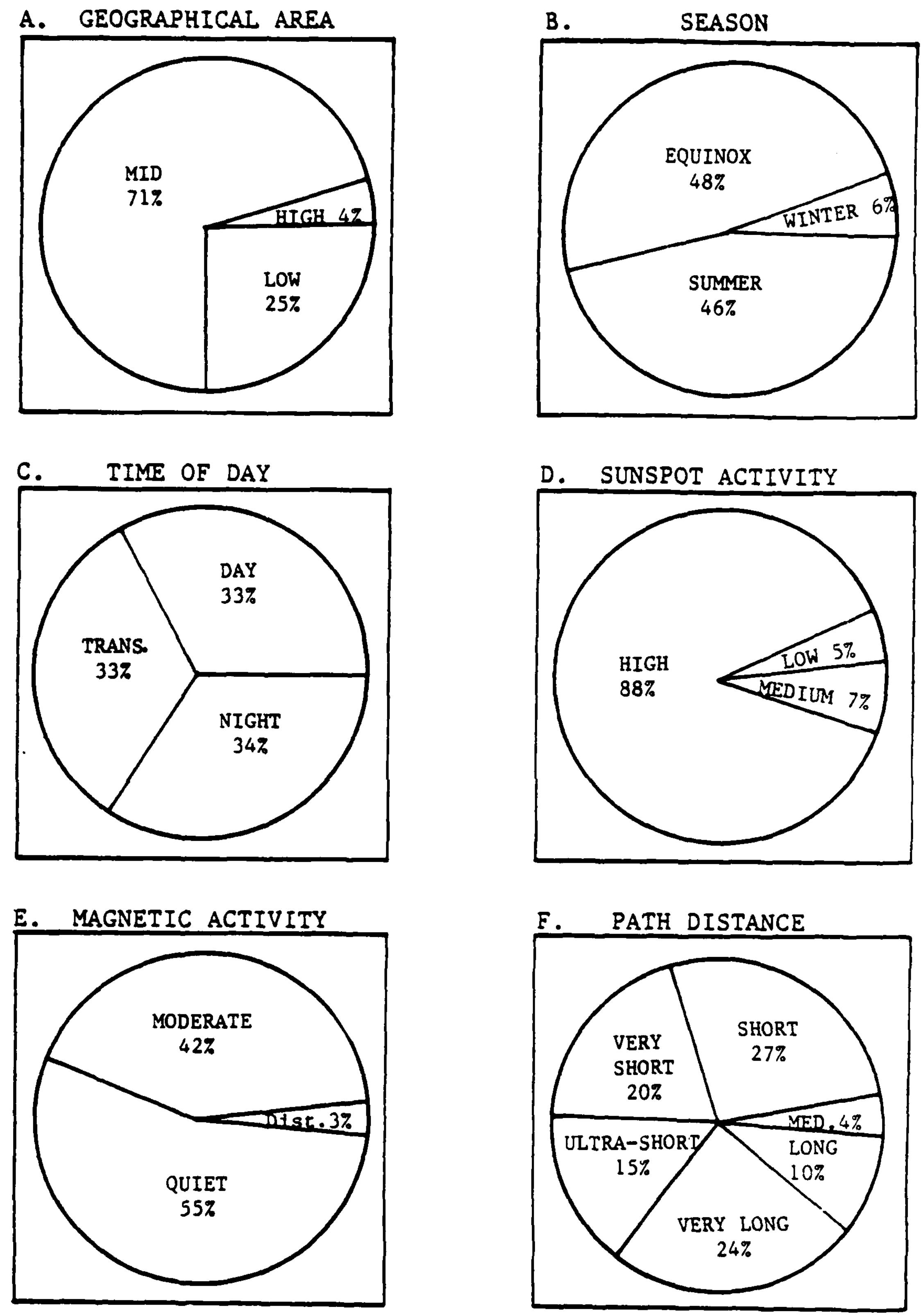


Figure 23. Pie-chart distributions of ionogram data from test operations from 1980 through 1982.

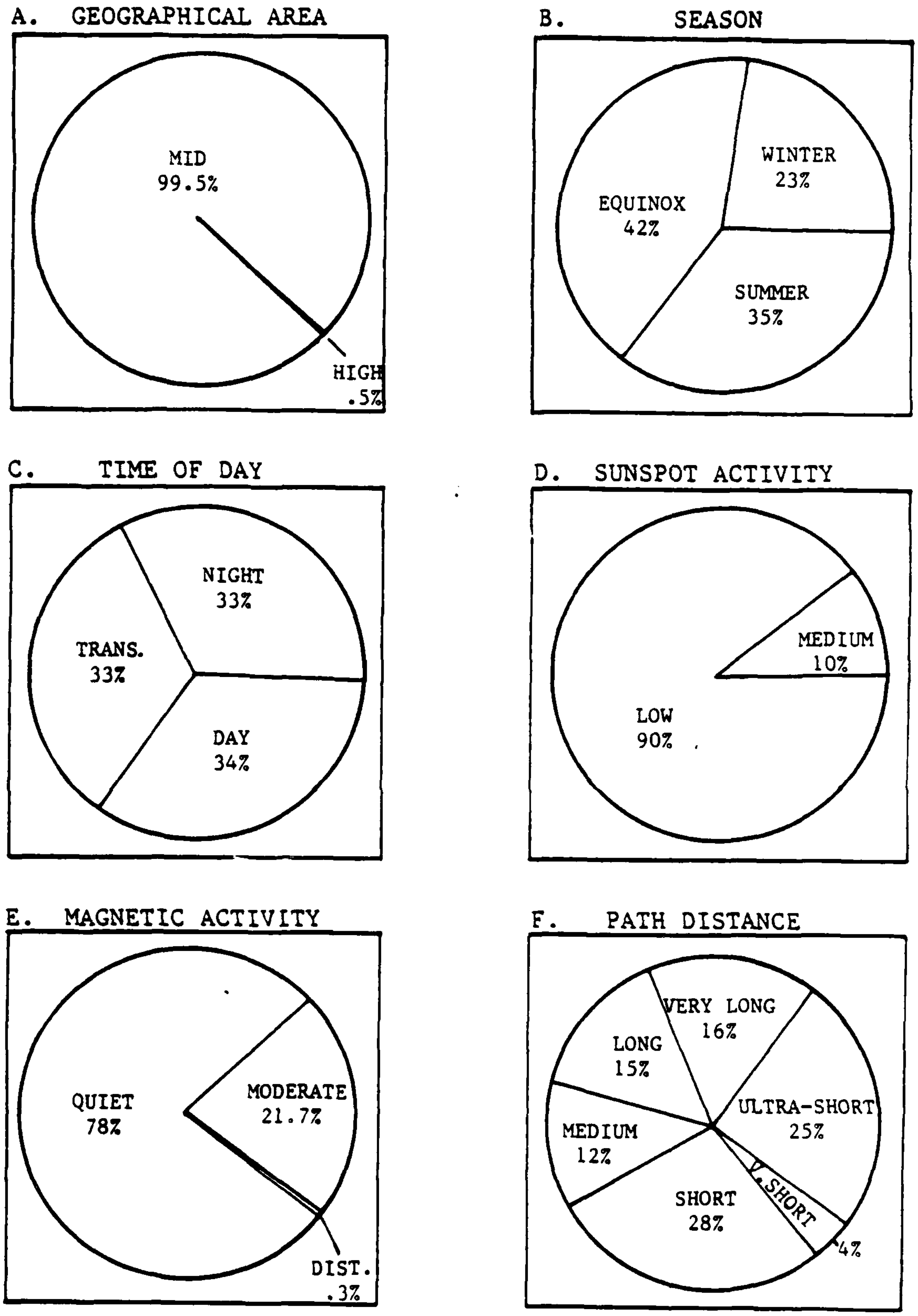


Figure 24. Pie-chart distributions of ionogram data from test operations from 1986 through the present.

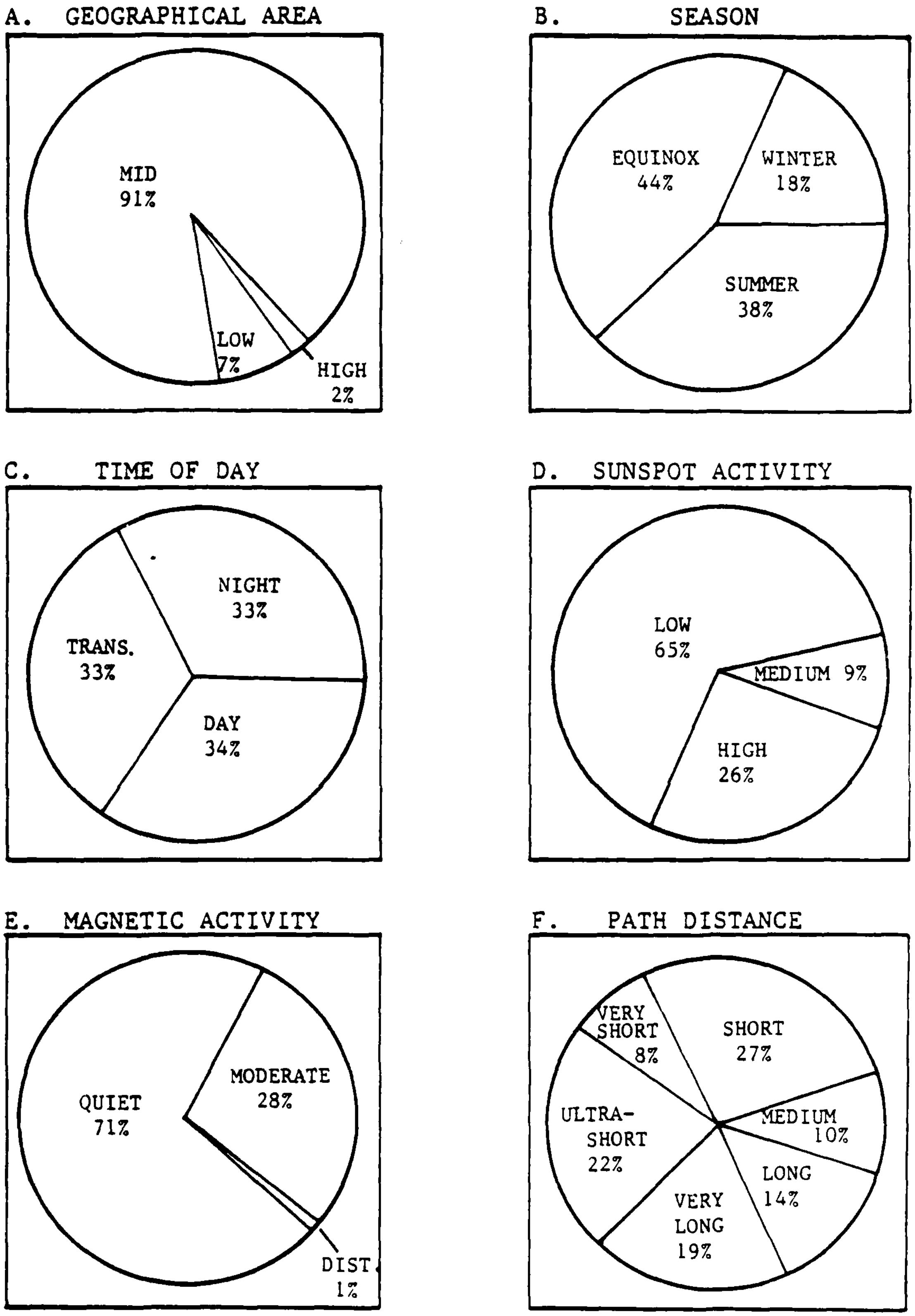


Figure 25. Pie-chart distributions of ionogram data from all test operations.